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FINDINGS IN A DENTAL SURVEY OF 354 PREPARATORY SCHOOL BOYS[1]

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In 1938 an investigation of various medical, psychological, and anthropological aspects of a group of students entering the first year class at a boys' preparatory school was begun, and during the next 2 years the members of each entering class were added to the survey. A thorough dental examination of each student was included as a part of the study of every individual in order to determine his dental status, to investigate the desirability of giving a thorough dental examination to members of such a group, and to determine what relationships might exist between certain of the dental data and the material derived from other parts of the survey. This report is concerned only with presenting a statement of our findings at the initial dental examination of 354 boys, and offers an opinion in regard to the desirability of giving such an examination to students of this economic level. In most institutions, and also in many colleges, some sort of dental inspection is made at the time of the annual medical examination: the report by Diehl (1) indicates the kind of findings which result from the dental examination of college students. Various community studies, notably that at Hagerstown by Klein and Palmer (2) have also been made, and indicate the amount of dental disease to which attention can be called, but variations in the criteria and the techniques employed have made it difficult to compare the results of many surveys.

One hundred and three students, who were entering the first year class at the school were selected for the first group to be studied; in 1940 the 117 members of the first year class were examined, and in

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1941 all 134 members of the first year class were included. These students ranged from 12 to 16 years of age (Table I), came from 29 states and 5 foreign countries (Table II). The parents of these students had incomes much higher than that of the general population (Table III): the information in Table III was obtained from confidential questionnaires, and the approximate percentages are as accurate as data of this type permits.

Each of these students has been, or will be, re-examined during each of his years at school; this report, however, is concerned only with the results of our first examination. It should be emphasized that this is a

TABLE I

Age distribution

	12	13	14	15	16	TOTAL
Group A	0	2	52	45	4	103
Group B	2	26	46	40	3	117
Group C	0	20	66	41	7	134

TABLE II

Geographic distribution

	MASS.	N. Y.	CONN.	PENNA.	N. J.	ILL.	OTHER STATES	FOREIGN
Group A	35	24	18	2	8	3	12	1
Group B	44	25	11	6	3	5	19	4
Group C	58	24	17	5	2	6	20	2

report of the initial dental examination of unselected groups from which no individuals falling at the extremes of caries susceptibility have been excluded and that no comments regarding factors in caries susceptibility are being discussed at this time.

METHOD

Charting

Data pertaining to teeth were recorded on Bodecker (3) geometric charts, in which each tooth is divided into its surfaces available for attack. This chart indicates that most teeth have 5 surfaces available for attack, that the upper first and second molars have 7 surfaces, and the upper third molars and all lower posterior teeth have 6 surfaces. On these charts caries experience may be expressed in terms of surfaces involved, and the

errors which follow when caries is expressed in terms of fillings, which often vary in size from a pit to a restoration of most of the tooth, can be avoided. When all teeth are present each case has 176 surfaces available for attack, but it should be pointed out that in this age group few third molars have erupted, and the number of surfaces in many cases is less than that number. Deciduous teeth were not considered in this survey and caries in them was not recorded. In Table IV are enumerated the extracted teeth, teeth with crowns, root fillings, retained deciduous roots, teeth which are congenitally absent, and unerupted teeth.

Caries has been considered to be in one of 3 categories: caries of the enamel (4), caries of the dentin, and recurrent caries. Caries of the enamel was considered to be present when there was enamel-etching, pits, breaks in the continuity of the enamel, or denuded

TABLE III

Economic distribution

	$1,500	$1,500–$3,000	$3,000–$20,000	over $20,000
Group A	5%	9%	66%	20%
Group B	5%	12%	63%	20%
Group C	5%	15%	60%	20%

TABLE IV

	SERIES A	SERIES B	SERIES C	TOTAL
Number of students	103	117	134	354
Number of extracted teeth (includes 1st molars and 3rd molars)	12	19	23	54
Number of extracted 1st molars	4	7	8	19
Number of crowns	3	2	4	9
Number of root canal fillings	3	1	8	12
Number of congenitally absent teeth (includes 3rd molars)	37	24	13	74
Number of unerupted teeth (includes 3rd molars)	377	439	572	1388
Number of retained roots	0	2	4	6

hypoplastic areas; white chalky areas with places of diminished translucency were not recorded, but all other defects were recorded as caries because we believe that defects in the enamel represent vulnerable areas although they may not be the result of caries destruction. Cavitation reaching the dentinoenamel junction or beyond, as observed by manual examination alone or with the aid of radiographs, was recorded as caries of the dentin. Leaky margins of fillings, especially where the cavity preparation was not extended to include grooves or self-cleansing areas, were charted as recurrent caries.

Occlusion was rated as normal, Class I, Class II, or Class III: this rating was based on Angle's (5) classification. Occlusion was considered to be normal when the position of the first permanent molars, permanent canines, and all other teeth were in their natural mesio-distal and bucco-lingual relationship. Class I occlusion was represented by a

normal mesio-distal relationship of the lower teeth and arch to the upper, but with malposition of one or more teeth. Distal relationship of the lower teeth and jaw to the upper was considered to be Class II occlusion. When there was a mesial relationship of the lower teeth and jaw to the upper, the occlusion was rated as Class III. At the time of the examination each student was asked whether or not he had ever had his teeth straightened or had appliances for correction; if the student was being treated that fact was recorded; if malocclusion was noted and treatment considered advisable, arrangement was made for consultation with an orthodontist.

Oral hygiene was rated good when tissues had a normal color, were free from debris, and showed evidence of regular and satisfactory care; if materia alba was present at the gingival margins and the teeth and tissues showed lack of care, the hygiene was rated fair; when the mouth was unclean, with accumulation of debris and stain on the teeth, the hygiene was considered poor. Observations on the periodontium were limited to signs of gingivitis, hypertrophy and atrophy; if these conditions were absent the periodontium was considered normal.

The consistency of the saliva was recorded as viscous, thin, abundant, or scanty. This rating was based on the examiner's observations and no special tests were made, and no attempt was made to induce salivation.

Each submaxillary area was palpated in order to detect the presence or absence of swelling. If swelling was present its degree was rated as slight, moderate, or marked.

Clinical Examination

A complete intra-oral radiographic examination was made for each student; this consisted of 14 films of the regular type and 2 bite-wing films. The radiographs were mounted and on hand for reference at the time of the manual examination; Burket (6) has demonstrated the importance of employing radiographs as an aid to the physical examination for caries. All radiographs and all the dental observations on these students were made by the same examiner; this obviated the differences in evaluation which might occur should more than one examiner be employed, and insured more constant and uniform observations. The manual examinations, which were not made until the radiographs had been evaluated by the examiner, were carried out with the subject seated in the dental chair in front of a window, and additional artificial illumination was available. New mirrors and sharp explorers, (Grafrath 17S and 9W10) were used to inspect the teeth; questionable areas of involvement were dried with cotton and air syringe, a technique which Sognnaes (7) has shown to be important. All charting was done by the examiner, and the radiographic and manual findings were compared by him at this time.

CLINICAL DATA

In this report our figures represent the findings at the time of the initial examinations of the members of the first year class in three consecutive years; these groups are referred to as Series A, B, and C. The data is presented in tabular form so that the caries experience of the 3 classes may be compared. Subsequent examinations have been, and will be made from year to year in an effort to determine the caries experience of these groups while they are in the school environment, but the present report is concerned only with their initial examination.

Enamel Lesions: Table V shows the distribution of unfilled lesions in the enamel for Series A, B, and C. It will be seen that while Series A and B had an average of 5.5 and 4.8 lesions per case respectively, Series C had only 2.6 lesions per case; there were, also, many more individuals in Series C who had no lesions at all, and also no students in this series had very large numbers of lesions.

Dentin Lesions: The extent of dentin caries is shown in Table VI; the defects of dentin range from 2.4 to 2.8 surfaces affected per case, and there is only slight variation within the 3 series; but in Series C there was a greater proportion of individuals who had no lesions and a smaller proportion who had a large number of surfaces involved. These figures can be compared profitably with other surveys (8), (9),

TABLE V

Distribution of unfilled lesions in enamel

	SERIES A	SERIES B	SERIES C
Cases	103	117	134
Total surfaces attacked—all cases	568	573	355
Average surfaces attacked—each case	5.5	4.8	2.6
Cases with no surface attacked	2	7	17
Cases with 1–5 surfaces attacked	40	63	103
Cases with 6–10 surfaces attacked	41	37	12
Cases with 11–15 surfaces attacked	17	9	2
Cases with 16–20 surfaces attacked	2	1	0
Cases with 21–25 surfaces attacked	1	0	0

(10); in some other studies, what we have chosen to call caries of the dentin, have been referred to as cavities.

Since there is a considerable range of family income among members of this group, we will consider the effect of economic status on caries in detail in a subsequent report, but it may be of interest to note at this time that among the 58 individuals whose family incomes were less than $3,000, the average number of unfilled lesions in the dentin was 3.7 per boy, while among the 73 individuals whose family incomes were over $20,000, the average number was 1.8 per boy.

Total Present Caries: The figures for total *present* caries represent the sum of surfaces found to be involved by lesions of the enamel, dentin, or recurrent caries at this initial examination. Table VII is the summary of the present caries experiences of the three groups; it

should be emphasized that filled lesions, which properly refer to *past* caries experience, are not included in this summary. In the 58 individuals in the lower income group the average number of total present caries was 9.6 per boy, and in the higher income group the average number was 6.3 per boy.

TABLE VI

Distribution of unfilled lesions in dentin

	SERIES A	SERIES B	SERIES C
Cases	103	117	134
Total lesions—all cases	298	338	327
Average number of lesions—each case	2.8	2.8	2.4
Cases with no surface attacked	35	33	58
Cases with 1–5 surfaces attacked	49	69	56
Cases with 6–10 surfaces attacked	16	8	14
Cases with 11–15 surfaces attacked	16	3	4
Cases with 16–20 surfaces attacked	1	4	1
Cases with 26–30 surfaces attacked	0	0	1

TABLE VII

Distribution of total present caries

	SERIES A	SERIES B	SERIES C
Cases	103	117	134
Total present caries: enamel, dentin, recurrent lesions	971	990	758
Average number of surfaces attacked—each case	9.4	8.3	5.6
No surfaces attacked	2	2	11
1–5 surfaces attacked	23	37	71
6–10 surfaces attacked	26	42	35
11–15 surfaces attacked	30	23	10
16–20 surfaces attacked	14	3	4
21–25 surfaces attacked	4	6	0
26–30 surfaces attacked	2	4	1
31–35 surfaces attacked	1	0	1
36–40 surfaces attacked	1	0	1

Fillings. (*Surfaces Filled*): The average number of surfaces filled range from an average of 9.2 to 13.2 surfaces per case (Table VIII), and it is interesting to note that in Series C we find the greatest average number of filled surfaces, and also more individuals with large numbers of filled surfaces. It would seem possible that the relatively smaller

number of unfilled lesions in enamel and dentin which were found in Series C can be explained in part by the relatively greater number of filled surfaces for this series.

TABLE VIII

Distribution of surfaces filled

	SERIES A	SERIES B	SERIES C
Cases	103	117	134
Total surfaces filled—all cases	953	1296	1772
Average number surfaces filled—each case	9.2	11.1	13.2
No surface filled	6	11	7
1–5 surfaces filled	25	18	34
6–10 surfaces filled	37	40	30
11–15 surfaces filled	19	14	23
16–20 surfaces filled	11	12	13
21–25 surfaces filled	3	14	11
26–30 surfaces filled	0	4	7
31–35 surfaces filled	1	1	2
36–40 surfaces filled	0	2	1
41–45 surfaces filled	1	1	3
46–75 surfaces filled	0	0	3

TABLE IX

Occlusion

	SERIES A		SERIES B		SERIES C	
	Number	Per cent	Number	Per cent	Number	Per cent
Cases	103		117		134	
Normal	57	55	68	58	62	46
Class I	31	30	32	27	52	40
Class II	12	12	14	13	15	11
Class III	3	3	3	2	5	3
Need treatment	10	10	16	13	18	13
Have been treated	18	17	19	16	27	20
Being treated	18	17	14	12	29	21

Occlusion: Table IX gives the distribution of various types of occlusion in the 3 series and includes data on the number of individuals who have been treated and who need treatment. The per cent having normal occlusion in the three series is 53. This figure includes those who now have normal occlusion following orthodontic treatment, and

TABLE X

Additional data

	SERIES A	SERIES B	SERIES C	TOTAL
Number in series	103	117	134	354
Hygiene				
Good	83	99	108	290
Fair	16	14	18	48
Poor	4	4	8	16
Not recorded				
Periodontium				
Normal	93	109	123	325
Gingivitis	6	8	10	24
Atrophy				
Hypertrophy	4		1	5
Not recorded				0
Saliva				
Viscous			11	11
Thin		18	2	20
Abundant		93	121	214
Scanty		6		6
Not recorded				103
Deposits				
None		112	133	245
Salivary		4	1	5
Serumal		1		1
Not recorded				103
Dental care needed				
Routine	80	95	115	290
Urgently	23	22	19	64
Dental care				
Regular		112	126	238
Occasional		5	8	13
Emergency				
Not recorded				103
Glands				
Normal		111	133	244
Slightly swollen		6	1	7
Moderately swollen				
Markedly swollen				
Not recorded				103

represents a group who presumably had malocclusion to some extent previously. Thus this group is not wholly composed of cases who never had malocclusion, i. e., were normal from birth. The per cent

having normal occlusion from birth is slightly lower and approximates the findings at Forsythe Dental Infirmary (11).

Additional Data: In Table X data concerning oral hygiene, periodontium, saliva, salivary deposits, and adenopathy are recorded for each of the series; in the same table we have listed the number of individuals in each series who have been advised to seek dental care either immediately or in the near future. It is evident that the majority of individuals showed good dental hygiene, normal periodontium, and have had regular dental care.

SUMMARY

1. A report of the physical and roentgenological findings at an initial dental examination of 354 boys ranging from 12 to 16 years of age and belonging to a higher economic level than that of the general population has been presented. No attempt has been made in this paper to correlate various parts of the data or to investigate causes of caries susceptibility, but mention has been made of facts which indicate that members of the low economic group showed a greater number of unfilled lesions in the dentin and a greater number of total *present* caries than did those of the higher income group.

2. The incidence of extracted teeth, 0.15 per boy, was found to be very low.

3. The number of unfilled lesions in the dentin was approximately two and

4. The average number of filled surfaces was about eleven per boy.

5. About 18 per cent of the students were found to require immediate dental care.

6. Normal occlusion was found in 53 per cent of the boys examined and 12 per cent were advised to have orthodontic treatment.

7. From this data it would appear that the inclusion of a careful dental examination as a part of the yearly routine medical examination of preparatory school boys is a valuable procedure.

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STUDIES OF THE EFFECT OF INGESTION OF CITRUS FRUIT ON THE ORAL MICROBIAL FLORA[1]

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Considerable attention has been given to study of the relation of diet to dental health. Hanke and co-workers (1929, 1930, 1933a, 1933b) observed that dental disorders almost invariably occurred in persons consuming a diet deficient in vitamins. Vitamin C was believed to be the significant factor. McBeath and Zucker (1938), McCollum (1937) and Mellanby (1926) have stressed the importance of vitamin D. Jay (1940), however, stated that dental caries is not a manifestation of malnutrition, that it cannot be controlled by addition of minerals and vitamins to the diet, but by restriction of carbohydrate in either adequate or inadequate diets.

Although proper diet is apparently expedient for healthy dental tissues, the role played by bacteria in various oral diseases cannot be overlooked. Hartzell and Henrici (1917, 1919) stated that oral streptococci are the etiological agents in dental caries, pulpitis, alveolar abscess and periodontal disease. Some workers have attributed the cause of dental caries to oral lactobacilli. Simmonds (1938) has suggested that in caries-susceptibles all sweet foods should be reduced to a minimum, thus keeping the oral flora low in those organisms known to be acid formers. Hadley (1933) observed that by reducing the carbohydrate in the diet the incidence of oral *L. acidophilus* could be decreased.

Large numbers of microorganisms are almost invariably present in the mouth. It would seem a valuable aid in the maintenance of oral health if some inhibition of microbial growth could be effected, either through diet or mouth hygiene. Howitt and Fleming (1930) and Howitt, Fleming and Simonton (1928) believed that oral bacteria were

[1] Received for publication March 13, 1941; revised by authors October 9, 1941.

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influenced more by food remnants in the mouth and by mouth hygiene than by general systemic reactions. Tucker (1932), examining 422 children, found aciduric streptococci in the mouths of practically all individuals regardless of the ingestion of citrus fruit juice. Leonard and Feirer (1927) found that none of 41 different commercial dentifrices tested effected any significant reduction in the bacterial content of mouth washings.

Although investigators believe that a properly balanced diet is important during the actual formation of teeth, it has not been definitely shown whether this fact holds true after the complete eruption of teeth. Fully formed teeth are generally regarded as being entirely separate from the rest of the body and consequently independent of bodily reactions. Bodecker (1932), however, has demonstrated that fluids may flow from dentin to enamel thus uniting the enamel with the vascular system of the body through "dental lymph". He maintained that metabolism is active in teeth and that nutritive material for the teeth was furnished by the dental pulp. Bodecker stated that the nutritive fluid ("dental lymph") of the teeth originates in the blood of the dental pulp and is secreted by the odontoblasts of the pulp. He listed 3 possible functions of the dental lymph in the teeth of children and adults: (1) to complete calcification of newly erupted teeth by furnishing mineral salts and fats, (2) to serve as a buffer against external acids, and (3) to inhibit the growth of oral aciduric microorganisms.

In a previous study (1941) of the effects of the local application of citrus fruit juices on the oral flora and saliva, it was found that orange and grapefruit juices exerted a definite inhibitory action on microbial activity. An increase in buffer capacity of saliva was also observed when citrus juice was used as a dentifrice and mouth wash.

A series of cooperative studies has been made to determine the influence of the actual ingestion of citrus fruit on both dental and general health. Investigations have included study of (1) changes in the microbial flora of the mouth, (2) effect upon the buffer value of saliva, (3) changes produced in the dental tissues, (4) the general physical effects in the body, and (5) vitamin C assimilation. The present report deals primarily with the study of the influence on the microbial flora of the mouth when citrus fruit was added to an otherwise normal diet.

EXPERIMENTAL

Materials: Two groups of individuals were used for the tests: one to be fed fresh grapefruit in addition to the daily diet and the other to receive no special allotment of citrus fruit and to serve as a control. Inmates of the District of Columbia Penal Farm, Lorton, Virginia were selected for study. This group of men proved particularly favorable because of convenience in the study and also from a nutritional standpoint. The men were available at all times for examination, and the distance between the institution and the laboratory was such that the analyses could be started within a relatively short time after the material for examination was collected. Any previous dietary or nutritional variations that might have affected the results were believed to be eliminated by the selection of men who had been on the regular prison diet for at least one year and who would remain under term for the duration of the study.

Cooperation in the investigation was entirely voluntary on the part of the inmates. The ages of individuals selected ranged from 19 to 58 years, both white and negro men being included. Data were obtained on 131 men, 64 of whom served as the control group, and 67 as the test group. The men in both groups received the regular prison rations, but the test group was fed, in addition, ½ of a grapefruit 3 times a day, the fruit being served with each meal. All fruit used in the study was grown in Florida, and purchased on the open market.

Collection of Saliva Samples: Examinations were made on samples of saliva obtained at regular intervals. Flow of saliva was stimulated by chewing sterile paraffin, and approximately 25 cc. of the saliva were collected from each subject into sterile sputum bottles. The saliva samples were always collected at approximately 10:00 A.M. on the test days, and packed in an iced container for transportation to the laboratory. An interval of about three hours occurred between the time of sampling and the time of bacteriological analyses.

Analyses of Materials: An initial examination of the oral flora of most of the individuals of both groups was made previous to the feeding of grapefruit to the test group. Immediately following the primary estimations of numbers and types of bacteria the test group then began to receive its daily quota of grapefruit. Samples of saliva were subsequently collected once a month from each member of both groups. Analyses extended over a period of 6 months.

Media: All samples of saliva were diluted with sterile water, dilutions of 1:100,000 and 1:1,000,000 being found adequate for all plating purposes. The 2 dilutions were plated in the following media: (1) plain nutrient agar, to determine total numbers of the general saprophytic types, (2) neopeptone tomato juice agar (pH 6.6), for aciduric organisms, (3) blood agar, for those organisms requiring animal protein for growth. Veal infusion agar (pH 7.4) was used as the blood agar base, 5 per cent sterile defibrinated horse blood being added aseptically to the medium just before use. Nutrient agar plates were incubated for 48 hours at 37°C.; tomato juice and blood agar plates were placed in an atmosphere of 10 per cent CO_2 and incubated for 5 days at 37°C.

RESULTS AND DISCUSSION

Data on the bacteriological examinations of 131 men employed during this study are presented below. Nine additional men obtained paroles or were forced to drop out because of prison restrictions before

some of the tests were completed. Therefore the results on those 9 individuals were incomplete and are not included.

The per cent of total individuals showing a decrease below their original count for both the grapefruit and the control groups is shown in *fig. 1*. The averages of the totals rather than a grand total (obtained by adding the three counts on different media, together) were used since some duplication of types undoubtedly occurred on the different media. Changes in numbers of living bacteria in the mouth are equally as significant as the magnitude of the numbers, so that the number of individuals showing an increase or a decrease in count is important in evaluating the influence of the test condition.

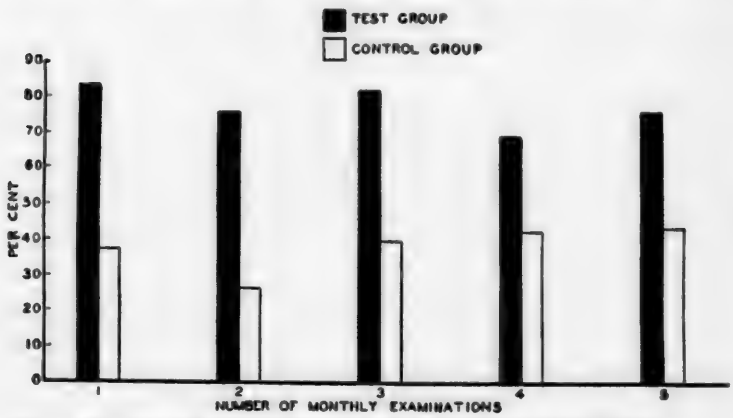

FIG. 1. Percentage of individuals showing decreases in count below initial.

Three fourths or more of the individuals in the test group showed a decrease in oral microbial count, whereas in the control group only 30–40 per cent showed a decrease, i.e. 60–70 per cent showed an increase.

Grapefruit was first added to the diet of test individuals during the second week of January, when colds and other respiratory infections were on the increase. Initial examination[3] of the men showed that vitamin C levels in the blood were low. The average ascorbic acid

[3] Vitamin C determinations of the grapefruit, blood plasma and urine were made by Drs. M. A. Elliott and A. L. Sklar, National Bureau of Standards. Their data are in press.

concentration of 140 men in the institution was only 0.4 mg. per 100 ml. of plasma. Since the optimal level of ascorbic acid in the blood is generally considered to be about 1.0 mg. per 100 ml. of blood plasma, it was apparent that men used in the experiment were deficient in vitamin C at the outset. A carefully planned diet is fed the inmates at the reformatory, yet the low vitamin C concentration showed the lack of foodstuff rich in this vitamin. This was indicated when periodic examination showed that the ascorbic acid level of the blood of men receiving grapefruit reached a maximum value of 1.1 mg. per 100 ml. of plasma after 3 months of feeding.

A decrease in count below the initial was maintained by 81 per cent of the test individuals after 3 months on the grapefruit diet as compared to 39 per cent of the controls. This is highly significant and indicates that the bacterial contamination of the mouth may be altered by daily ingestion of grapefruit. The percentage of men in the test group showing decreases in counts was not as great after the fourth and fifth months (*fig. 1*). This was concurrent with a lowering of the average ascorbic acid level of both the blood and of the urine at this period. The introduction of fresh vegetables to the diet during these months was apparently without effect as far as maintenance of vitamin C level was concerned. An increase in vitamin C in the diet is apparently expedient during the warm months for maintenance of an optimal concentration of ascorbic acid in the body. These findings are in accordance with the work of Belser, Hauck and Storvick (1939) who observed that, under a constant intake, the ascorbic acid content of urine is less during hot weather than in cold.

In Tables I and II the average count of all individuals in the respective groups is given for each medium employed. The average counts of the test group are markedly lower than those of the controls. The percentage decreases in bacterial counts below the initial of the mouths of the test group compared with the control group are shown for the three media in *figs. 2, 3* and *4*.

Fig. 3 indicates the decreases found when using blood agar. This medium supports the growth of a number of potential pathogens. Their presence in the mouth should be regarded as possible agents in oral diseases.

Hartzell and Henrici (1917) concluded that streptococci of the viri-

dans type, because of their constant presence, their invasive power and high acid production, were the cause of dental decay. This view was also shared by Tunnicliff and Hammond (1938) who found a rough greening streptococcus predominating and often the only organisms to be present in tubules of the dentin. Anderson and Rettger (1937) believed that streptococci were important in caries and attributed their role to the presence of a higher protein content of the dentin which furnished optimal environment for their growth. It is possible

TABLE I

Effect of ingestion of grapefruit on the bacterial content of the mouth

(Each figure represents the average of all counts of all individuals in test group)

MEDIUM (AGAR)	TOTAL NUMBERS OF BACTERIA PER CC. OF SALIVA					
	Initial count	After following interval on grapefruit diet:				
		1 month	2 months	3 months	4 months	5 months
Plain nutrient..	48,238,000	26,356,000	29,681,000	28,344,000	35,093,000	29,392,000
Tomato juice...	33,780,000	13,831,000	30,935,000	20,961,000	20,815,000	25,644,000
Blood.....	104,655,000	67,728,000	58,439,000	61,719,000	68,681,000	84,892,000

TABLE II

Results of bacteriological examination of saliva of control group

(Receiving no grapefruit)

MEDIUM (AGAR)	TOTAL NUMBERS OF BACTERIA PER CC. OF SALIVA					
	Initial count	After following interval:				
		1 month	2 months	3 months	4 months	5 months
Plain nutrient..	41,259,000	54,184,000	46,469,000	43,653,000	54,529,000	54,368,000
Tomato juice...	20,685,000	45,438,000	47,229,000	36,081,000	34,663,000	30,375,000
Blood.....	96,948,000	91,408,000	101,840,000	83,615,000	87,588,000	84,523,000

that the presence of streptococci in dentin and pulp may act as a focus of infection, which may eventually give rise to periapical infection, abscesses, and even extend to the general system.

The marked reduction in bacterial counts of the test group obtained on blood agar thus becomes highly significant. Slight decreases in counts below the initial on blood agar occurred in the control group at the first, third, fourth and fifth monthly examinations, respectively, while a 5 per cent increase resulted at the second month.

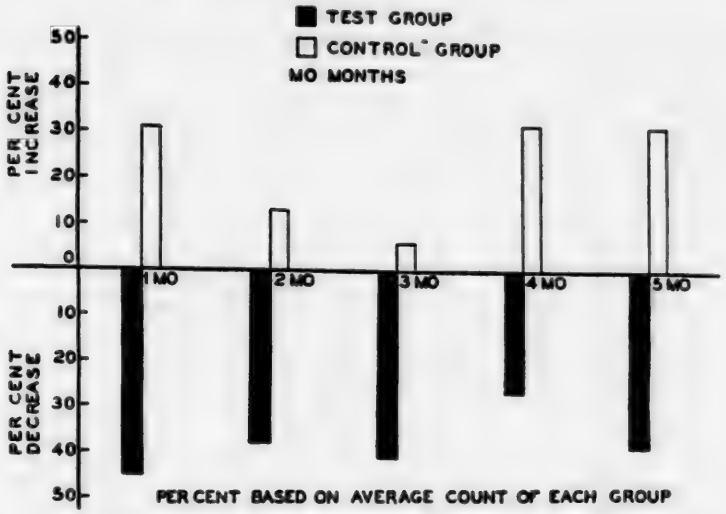

FIG. 2. Relative change from initial bacterial counts in test and control groups. A. Plain nutrient agar.

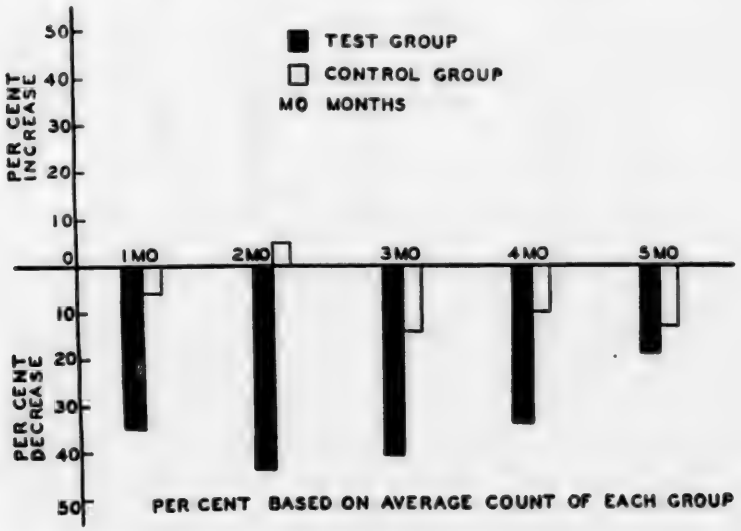

FIG. 3. Relative change from initial bacterial counts in test and control groups. B. Blood agar.

Results obtained on tomato juice agar for the test group were not as consistent as those on the other media, but decreases in counts below the initial occurred at each examination (*fig. 4*). On the other hand, marked increases in the average counts occurred on tomato juice agar for the control individuals at each monthly examination. The growth of oral aciduric microorganisms was very much favored by tomato

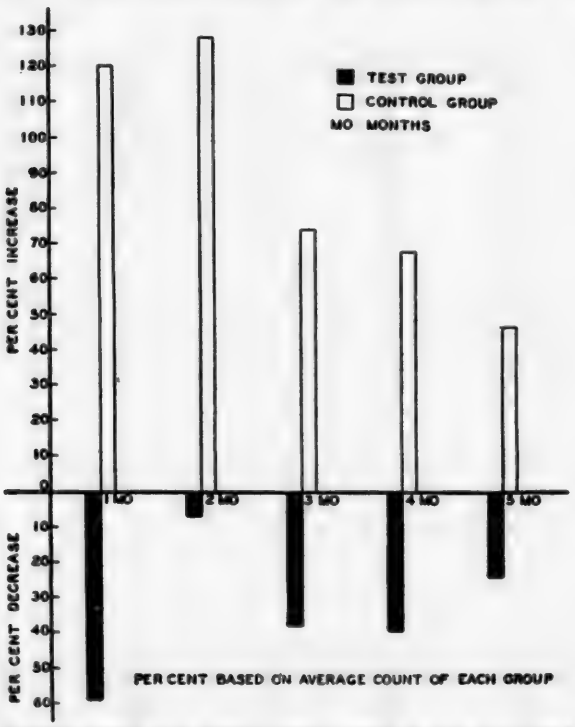

FIG. 4. Relative change from initial bacterial counts in test and control groups. C. Tomato juice agar.

juice agar. It is maintained by some workers that these organisms play a role in dental decay. If this theory is correct, inhibition of growth of these microorganisms would aid in caries treatment, so that the decreases in counts of aciduric bacteria presented by test individuals may indicate a controlling influence of importance.

The magnitude of the changes in the different types of organisms

has been determined as the averages of the counts of all individuals at each month on each culture medium. They are shown in *fig. 5*.

Physical and dental examinations of the men were made at the start of the investigation and at regular intervals throughout.[4] All individuals on the grapefruit diet showed considerable improvement in general health. Increase in appetite was observed, bowel elimination was improved, and a number of men who had previously complained of constipation were greatly relieved when grapefruit was added to

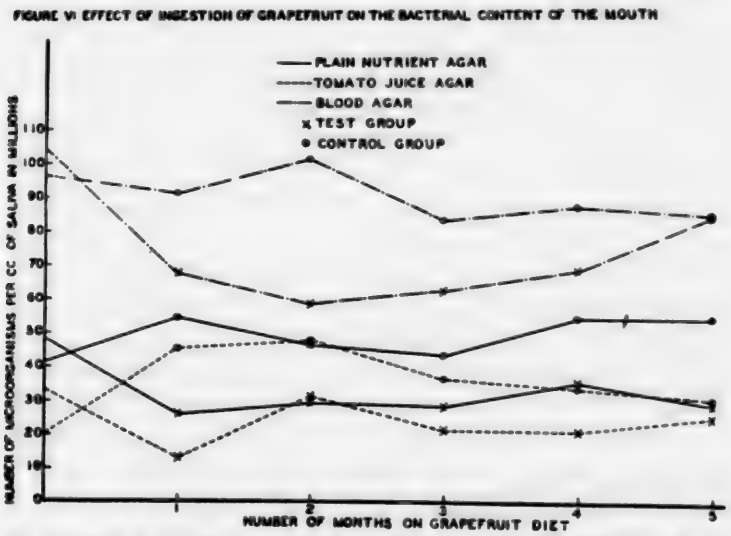

FIG. 5. Effect of ingestion of grapefruit on the bacterial content of the mouth.

their regular diet. The men in the test group experienced a definite "lift", and expressed a feeling of well-being throughout the experiment.

The dental examinations indicated marked improvement in tone of oral tissues, and a number of severe cases of bleeding gingivae was checked in individuals receiving grapefruit. Some authors have maintained that the ingestion of citrus fruit over a period of time may have some decalcifying action upon the enamel of teeth. It was interesting

[4] Physical examinations were made by Dr. F. G. Klune, M.D. and dental examinations by Dr. G. W. Bogikes, D.D.S., District of Columbia Penal Farm. Their data are in press.

to observe, however, that the ingestion of 1½ grapefruit daily for a period of 6 months had no deleterious effect whatever upon the tooth enamel of any of the test individuals.

It was apparent that some dietary factor, or factors, supplied by grapefruit had influenced both the physical and dental conditions of test individuals. It is not definitely known, however, whether the change in oral flora was produced through the effect on the general system, or as a result of local environmental changes in the mouth. King, cited by Gies (1921), maintained that bacteria grew in an alkaline medium, and that an acid substance would inhibit their growth. Black, also cited by Gies (1921) stated that certain acids placed in the mouth tend to inhibit microbial action. These views would seem to indicate that local environmental changes produced by the ingestion of grapefruit were responsible for the decrease in bacterial counts of the mouth.

It was found by Elliott, Sklar and Acree (1941) that the average pH of the urine of test individuals was 0.5 units greater than that of the control group at the end of 6 months. No significant difference was observed between the average pH of saliva of the test group and that of the controls during the study. However, the average buffer value of saliva of test individuals was consistently higher than that of the controls. Considerable attention has been given to the study of physico-chemical properties of saliva in an attempt to find some difference that might explain caries activity. Titratable alkalinity, pH, CO_2 capacity, and calcium and phosphate content of saliva have been thoroughly studied as factors in dental caries. No consistent differences have been observed, and general disagreement among workers has warranted no definite conclusions. In a recent study Hanke (1937) emphasized the role played by the buffer capacity of saliva in caries. He observed that the saliva of individuals immune to caries was alkaline and well-buffered while the saliva of caries-susceptibles was usually acid and poorly-buffered. Although the exact cause responsible for the initiation of the carious lesion is still unknown, it is generally conceded that the decalcifying process is due to acids produced by certain oral microorganisms. We have observed that the buffer value of saliva was increased when citrus fruit was ingested. This fact becomes of importance in dental caries and may bear some

relation to its control. Any increase in the buffer capacity of saliva would correspondingly enhance its ability to neutralize mouth acids formed by bacterial fermentation.

SUMMARY AND CONCLUSIONS

The addition of grapefruit to the daily diet produced a marked decrease in bacterial numbers in the oral flora. The average bacterial count of the mouth was reduced 47 per cent in test individuals after they had received ½ of a grapefruit 3 times a day for 1 month. Monthly examinations of saliva showed that a reduction was maintained as long as individuals consumed grapefruit in addition to the daily diet.

In a previous study dealing with the local application of citrus fruit juices a corresponding inhibition of microbial growth in the mouth was manifested.

Similar results obtained with both methods of administration seem to indicate that citrus fruits possess some factor, or factors, inhibitory to oral bacteria.

It appears that reduction in bacterial numbers of the oral flora was due more to local influences of citrus fruit and fruit juices than to systemic involvement that may have resulted through their use.

The marked reduction of both pathogenic and aciduric microorganisms in the oral flora through the ingestion of citrus fruit becomes an important factor in the control of certain oral diseases.

This work was aided by a grant from the Florida Citrus Commission. It is a portion of an investigation carried out under the direction of a Research Advisory Committee consisting of Dr. Sterling V. Mead, D.D.S., Washington, D. C.; Dr. S. F. Acree, National Bureau of Standards; Professor L. H. James, Prof. of Bacteriology and Head of the Department; and Mr. L. W. Marvin, Florida Citrus Commission, Lakeland, Florida.

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HEALTH INDEX OF THE TEETH[1]

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In public health administration and practice the need is often felt for some simple, yet comprehensive, formula which would describe the state of health or illness of either groups or individuals. So far as the general public health is concerned, such a formula is not available. We are fortunate, in the field of dental public health, to find one at hand; a formula which describes the health status as related to dental caries. The initials, DMF, are now familiar to most dentists. They understand it to mean decayed (D), missing (M) and filled (F) teeth. It has been customary to express the total number of DMF teeth found in the total number of examined children and also as the number per 100 children. We suggest that there are certain objections, from a statistical standpoint, to the method as commonly used. It is our purpose to discuss these objections, and to offer certain modifications in the use of this most convenient term, DMF.

In numerous reports, great effort has been made to provide data upon the frequency of decayed, missing, and filled teeth among school children of various ages, residences and other demographic characteristics. Millions of children have been examined and the findings expressed in terms of DMF, yet the fundamental information resulting from these surveys has been relatively small. We believe that this may be due, in part, to the manner in which the data have been expressed. We suggest that to represent the dental health of children in terms of the number of decayed, missing and filled teeth per 100 persons examined is logically and biologically unsound.

In public health, it is usually the condition and the needs of the individual which cause concern. This holds true whether the re-

[1] Received for publication June 29, 1941.

[2] Now at W. K. Kellogg Foundation, Battle Creek, Mich.

quirements are for dental care, health education or other objectives of preventive medicine. This being so, it is desirable to know the number of children who are free from caries, past and present, separate and distinct from those who have or who have had the disease. It also is desirable, for certain purposes, to consider the tooth as a unit; to know how many teeth were or are decayed, filled, or extracted in a given sample of teeth. But the ratio of DMF teeth to children examined, as commonly used, combines both, so that instead of having two useful and important statistical units, we have no real value from either.

The DMF ratio, as it has been commonly used, is a *coordinated relationship*, corresponding to many demographic relations such as the number of new born or the number of traffic accidents to a given population. Contrasted to the coordinated is the *genetic relationship* which accounts for events and their effects within a consistent sample. In a *genetic relationship*, all units of the basic sample can be equally affected. In dental statistics, the genetic relationship should compare the number of DMF *teeth* with the number of teeth which have remained sound in a given sample, or the number of *children* who actually have DMF teeth with the number of *children* who possibly could have DMF teeth. To combine the two is not permissible.

When the number of DMF and sound teeth are considered, the ratio should be related only to the total number of teeth which have erupted[3] in the mouth of the examined children. However, when the rate of caries attack is considered, further difficulties occur, in using the DMF formula, because teeth erupt at different intervals, and therefore are exposed to caries attack for varying amounts of time. The probability of decay among different teeth varies. This difficulty can be overcome easily by the introduction of an exposure unit of time, a unit corresponding to the elapsed time since the tooth's eruption[4] (1). We will discuss this in a separate paper.

We repeat that, from a biological viewpoint, the individual as a

[3] In determining the number of erupted teeth, account must be taken of the number which have been extracted. In this discussion, we are only concerned with the permanent teeth.

[4] This was first mentioned and described by Palmer, Klein and Kramer in their study of school children in Hagerstown, Maryland.

whole, and groups of individuals are of primary interest. In agreement with this, we suggest that dental health statistics should consider the child as a biological unit: consider the complete dental apparatus as the unit rather than the individual teeth. We do not commonly determine and relate the condition of the separate parts of a given organ of the body in general public health statistics. For example, the number of lobes of the lung which may be diseased are not reported in describing lung diseases in the population; in the case of an individual who has 2 diseased kidneys, the count is not based on the *2* affected organs. We do not give the case with 2 affected organs twice the weight as the case with only 1 when accounting for the total number of cases of kidney or other diseases in a given sample of the population. We are primarily interested in the total number of persons with affected lungs or diseased kidneys, and so forth. The

TABLE I

DMF prevalence rates (permanent teeth) of North American Indian children (per cent)

Age Group in Years	6-7	8-9	10-11	12-13	14-15	16 and up
Cherokee	39	65	79	79	94	100
Navajo	13	20	36	44	54	50
Total of tribes	31	50	64	73	77	85

number of persons suffering from 1 or more affected lobes is only of secondary interest to the public health administrator. We are, from the public health standpoint, mainly interested in such statistics as make a clear distinction between the healthy and the ill, or between the healthy and some degrees of sickness. But in any event, it should always be possible to separate the number of healthy from the number who are ill. Such a distinction is not possible in most dental statistics. Such a clear and logical distinction cannot be made between the caries resistant and the caries susceptible individuals, when the caries ratio is of children having 0, 1, 2, or several decayed, missing, and filled teeth, as 1 group.

Klein and Palmer in their study of dental caries among the North American Indian recognize the need for some such distinction (2). They give an account of the prevalence rates of dental caries: the "prevalence rates being defined as the number of children, per 100

children examined, that had one or more teeth decayed, missing, or filled." In their series there were 8257 Indian children. Included in the group were children from at least 35 different tribes. In Table I we present the prevalence rates of two tribes, according to age, and also the rates when all the tribes were totaled. The values are illustrated graphically in *fig. 1*.

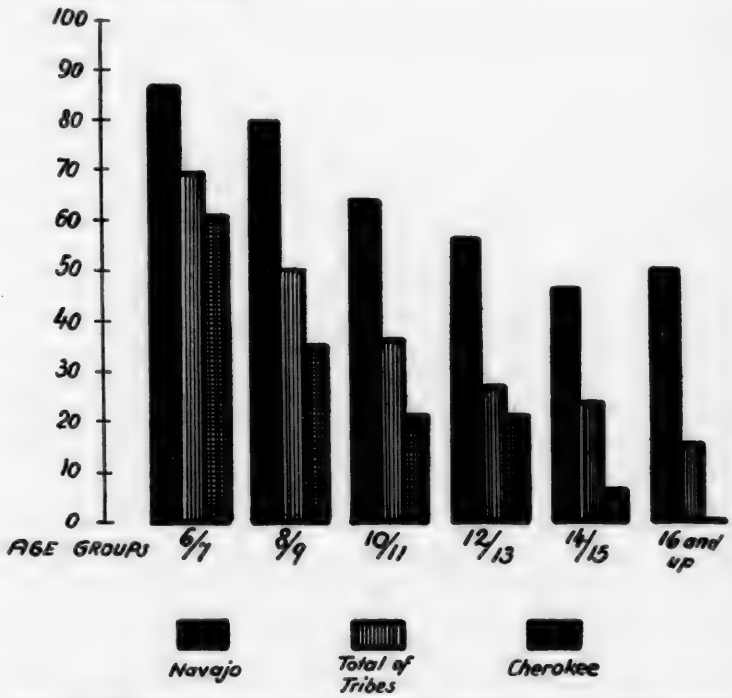

FIG. 1. Health index of permanent teeth among North American Indian children. Percentage of children without any DMF-teeth in different age groups.

From these values we have computed the rates of Indian *children* who had no DMF teeth. Our rate is the difference between the Klein and Palmer "prevalence rates" and 100. This ratio is a true "Dental Health Index" because it directly expresses the status of dental health and increases and decreases as the DMF increases or decreases, while the accumulated number of DMF, the prevalence rate, increased with decreasing health and vice versa.

Klein and Palmer believe that "although by such arrangement, important differences among the tribes in respect to numbers and percentages of children affected by dental caries is achieved, little information as to the degree of affection of the teeth themselves by caries is made available." For that reason, they give specific information as to "caries attack rates" in the teeth, expressed in terms of the "total numbers of decayed, missing, and filled permanent teeth per 100 examined mouths," and to "rates of severity of attack by caries," expressed in terms of the number of decayed, missing and filled permanent teeth per 100 mouths which had been attacked by caries.

We believe, as previously stated, that a valid attack rate can only be expressed by the number of DMF teeth per 100 *examined teeth* rather than mouths.

So far as the "rates of severity" are concerned, we propose that children with caries be divided into 2 groups: first, those with from 1 to 4 decayed permanent teeth, and second, those with more than that number. This will permit those children with *moderate* caries attack rates (those where caries probably involves only the first permanent molars) to be considered apart from those with *severe* attack rates (those children who probably have or have had caries in teeth other than first permanent molars).

As an example of the information which data, treated in this manner, will provide, we present Table II.[5] All values in the table are in terms of 100 examined children, and refer to permanent teeth only. In *fig. 2*, these values are shown graphically. In the bars the white spaces represent the decreasing values of the *Dental Health Index*, the shadowed and black spaces give a true picture of the attack rate. We have divided the attack rate into the 2 degrees of severity, a moderate attack (shadowed), where not more than 4 teeth are involved, and a severe attack (black), when more than 4 teeth are decayed, missing or filled. Because both the *Dental Health Index* and the caries attack rates are based upon the *same* number of children (not the one upon children, and the other, upon teeth) we are able to combine or compare these rates directly.

[5] The data are from a survey of Bergen County, New Jersey, school children, conducted by practicing dentists, and made under the auspices of the New Jersey State Health Department. We are permitted to use the data through the courtesy of Dr. J. M. Wisan.

The theory of a Health Index was first developed by Roesle who wished to distinguish, in health statistics, first, the number of indi-

TABLE II

Health index and decayed, missing or filled (DMF—teeth) permanent teeth of 1005 school girls of Bergen County, New Jersey

Age in Years at Last Birthday	5	6	7	8	9	10	11	12	13	14	15	16	17
Children with no DMF (percent) health index	85	41	16	4	3	2	5	6	1	0	0	0	0
Children with 1–4 DMF	15	58	73	85	73	48	32	27	16	8	7	5	8
Children with 5 and more DMF	0	1	11	11	24	50	63	67	83	92	93	95	92
Total number of DMF teeth	29	172	279	350	396	511	589	687	849	1010	1069	1128	1153
Number of children examined	55	71	96	82	78	89	82	85	98	91	60	79	39

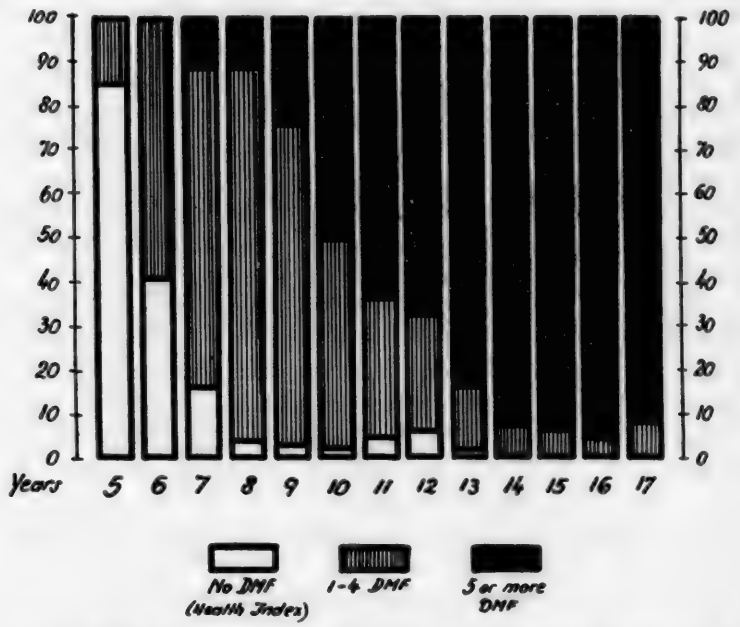

FIG. 2. Health index of permanent teeth among 1005 school girls in Bergen Co., N. J. Percentage of children without any DMF-teeth, or having 1–4 and 5 or more DMF-teeth, in different years of life.

viduals who had been well or sick during a given interval, and second, the number of times illness had recurred during the same period; between an individual who had been ill once (single morbidity) and

one who had been ill more than once (multiple morbidity) (3). One of us (K.P.) has extended the Roesle idea to apply to each general health status where we are able to contrast health and sickness or where we are able to distinguish some degree or degrees of sickness (4). We now apply the method to the severity of dental caries attack.

Klein and Palmer indicated the importance of the first permanent molars by preparing DMF ratios for these teeth alone, as well as the DMF ratio for all teeth in the Indian children. This permits a comparison of data based exclusively on the first molars and that based on all the teeth of the same children. The results of such a comparison appear in Table III.

TABLE III

DMF prevalence rates in permanent first molars and other permanent teeth of same North American Indian children

Age Group in Years	6–7	8–9	10–11	12–13	14–15	16 and up
Total of DMF teeth in mouths	578	1633	2489	3652	4051	4765
Total of DMF teeth among first permanent molars	549	1550	2014	2299	2035	1982
Total of DMF teeth among other permanent teeth than first molars	29	83	475	1353	2016	2783
Total of mouths with DMF permanent teeth	335	803	1019	1121	999	977
Total of mouths having DMF first molars	331	795	978	1009	886	828
Total mouths having DMF without first molar involvement	4	8	41	112	113	149

When we examine this table, we find that the first permanent molars have usually been involved when DMF teeth occurred. The data are so arranged that a comparison can be made between the number of DMF teeth when all the teeth are considered, and also when the first molars are considered separately. We believe it permissible to assume that in any group of children, aged 6 years or more, the first four reported DMF teeth will involve the four first permanent molars. It is appreciated that the currently used eruption tables record the lower permanent incisors as erupting at the same age, 6–7, as the first molars. However, we believe that caries in the incisors, during childhood, will not significantly change the importance of the first molars, as far as caries incidence is concerned. Tables II and III demonstrate that it

is only among the older children that permanent teeth other than the first molars become important factors in the total number of DMF teeth.

Because involvement of the first molars is an event so nearly universal in all children who have *caries*, we have designated the attack rates as *moderate*, when 4 or less DMF teeth occur per child. When more than 4 DMF teeth are reported per mouth, the event is so relatively rare that we have classified such an attack rate as *severe*. The permanent teeth, other than first molars, are apparently so resistant to caries attack that the attacks must be relatively severe to overcome their resistance.

It should be mentioned that we realize that when 4 DMF teeth per child are reported, in an age group of 7 years or under (other than the lower centrals) all erupted permanent teeth have been affected by caries. A discussion of possible explanations for this high susceptibility of first permanent molars to caries attack will be presented in another paper.

We suggest that it is important to consider the teeth of the child as the statistical unit. At the present time there seems to be no single descriptive term which is exclusively descriptive of the natural dental apparatus. The term, denture, has become so universally used to describe the mechanical apparatus to replace lost teeth that it is necessary to qualify the word "denture" with "natural" or some such term, so that there can be no confusion when referring to the natural teeth. "Dentition" is not entirely satisfactory for this purpose, because it is used to describe "the process or period of cutting teeth" or "the system or arrangement of teeth peculiar to an animal." We suggest that, for statistical purposes, "*Biodenture*" be used when referring to all the natural teeth in a mouth. This term will describe not only the accumulation of natural teeth in the mouth, but the organic system of teeth with all the major problems and metabolic, physiologic, and pathologic facts pertaining thereto.

SUMMARY

Modifications have been suggested in the use of the initials DMF (decayed, missing and filled teeth) so as to bring the statistics of dental

health into closer agreement with the statistical practices prevailing in other fields of human biology.

The possible advantages of these modifications have been illustrated with data from the United States Public Health Service and the New Jersey State Health Department.

A Dental Health Index has been suggested and a method described whereby the Health Index and the caries Attack Rates can be directly compared.

The term Biodenture has been suggested as suitable, for statistical purposes, to describe the accumulation of the natural teeth in the mouth with the major problems and the metabolic, physiologic and pathologic facts pertaining thereto.

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PULP STONES AND HYPERCEMENTOSIS IN ARTHRITIS[1]

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The purpose of this study is to determine whether any relationship exists between either pulp stones or hypercementosis and arthritis. Of 200 cases of arthritis studied at the Montefiore Hospital, 100 were edentulous and, therefore, of no value in this investigation. In the edentulous group, the results of prior extractions of all the teeth were disappointing; the arthritis still persisted. Only those cases which had at least 15 teeth, distributed between the maxilla and mandible, were included in the study. Forty-six of the remaining 100 arthritics met these requirements (Table I).

The arthritides are usually classified as non-specific and specific types. Under the non-specific are allocated the chronic infectious group (proliferative, atrophic, rheumatoid, arthritis deformans) and the degenerative group (hypertrophic, osteoarthritis). Under the specific type is found the tuberculous and gonorrheal arthritis. The greatest number of cases (37) belonged in the chronic infectious group, 6 in the degenerative and 3 in the specific groups (Table I).

A control series of 48 cases of so-called "healthy individuals" (non-arthritic) was selected at random from the Periodontia Clinic of the New York University College of Dentistry. Only those cases which presented at least 15 teeth distributed between the maxilla and mandible were considered (Table I).

An attempt was made to determine in what ratio pulp stones appeared in vital-carious teeth and non-carious teeth. However, the work was discontinued because pulp stones were found approximately equally in both cases.

[1] Presented at the 19th General Meeting of The International Association for Dental Research, St. Louis, March 15 and 16, 1941 (*J. D. Res.* 20: 287, 1941) and at a meeting of the New York Section, I. A. D. R., June 4, 1941 (*J. D. Res.* 20: 385, 1941). (Received for publication June 13, 1941.)

TABLE I

Occurrence of pulp stones and hypercementosis

ARTHRITIC GROUP				CONTROL GROUP			
Age	Sex	Teeth with pulp stones	Teeth with hyper-cementosis	Age	Sex	Teeth with pulp stones	Teeth with hyper-cementosis
31	F	4	0	41	F	2	0
13	F	0	0	22	F	5	0
41	F	3	0	45	F	2	0
27	M	0	0	49	F	0	0
57	F	0	0	44	F	3	0
40	F	0	0	19	F	2	0
44	M	0	22	32	M	0	0
50	M	0	2	42	M	0	0
51	M	0	0	45	M	0	0
28	M	3	1	49	F	0	0
54	M	2	1	46	F	2	0
63	M	0	0	47	F	1	0
20	F	0	0	37	M	1	0
27	F	0	0	64	F	0	0
45	M	0	0	36	F	0	0
40	M	3	3	39	M	0	0
43	M	1	0	28	F	0	0
50	M	2	4	41	M	0	0
54	F	0	0	40	F	0	0
51	M	0	1	31	F	0	0
48	F	0	3	58	F	0	0
59	F	1	0	35	M	2	0
24	F	0	0	28	F	2	0
20	F	0	0	27	F	1	3
54	F	0	0	27	M	2	0
40	F	0	0	25	M	1	0
42	M	2	0	57	F	2	2
29	F	0	0	16	F	0	0
53	M	0	0	21	M	0	2
60	F	0	1	31	M	4	2
27	M	7	0	18	M	0	0
44	M	0	0	34	F	8	0
48	F	1	0	53	F	0	3
44	F	2	0	45	M	5	0
35	F	0	0	31	F	0	0
53	F	0	0	28	F	0	0
64	M	0	0	48	F	0	2
14½	M	0	0	52	M	3	0
48	M	0	1	38	F	2	0
21	M	1	0	49	F	0	0
43	F	0	2	58	F	4	0
40	F	0	0	40	M	0	0
28	M	0	0	65	F	0	0
21	M	4	0	37	F	4	0
36	M	0	0	54	F	0	0
24	M	2	0	45	M	1	0
				45	F	0	0
				47	F	5	0

A tabulation of patients in both the arthritis and control groups according to sex and age was also made for statistical study and the results were noted (Table II). Another tabulation of patients in both arthritis and control groups relative to the number of cases of pulp stones and hypercementosis in each age group was also made for statistical study (Table III).

From these tables, a comparative study of the control and arthritic groups was completed and certain facts were determined and summarized (Table IV).

TABLE II

Tabulation of patients in both the control and arthritic groups according to sex and age

AGE GROUP	ARTHRITIC GROUP			CONTROL GROUP		
	Male	Female	Total	Male	Female	Total
13–21	3	3	6	2	2	4
22–30	5	3	8	2	5	7
31–40	2	5	7	6	7	13
41–50	8	5	13	5	11	16
51–60	4	6	10	1	5	6
61–65	2	—	2	—	2	2
Total.....	24	22	46	16	32	48

FINDINGS

1. Forty-eight control and 46 arthritic cases were studied. 2. The average age of both groups was 40. 3. The control group contained more female (32) patients than males (16). 4. In the arthritic group the sex was almost evenly divided (22 females to 24 males). 5. The number of cases with pulp stones, radiographically, was greater in the control group, although the average number of teeth affected with pulp stones in the positive cases was the same. 6. There were five more cases of hypercementosis, radiographically, in the arthritic group than in the control group. 7. The average number of teeth with hypercementosis was higher in the arthritic group. This was greatly influenced by one case of chronic infectious arthritis in which all the teeth (22) were affected. This was the only instance in either group with all teeth hypercementosed. 8. Pulp stones and hypercementosis appeared, radiographically, in the same individuals mouth

in only 4 instances in the arthritic group and in only 3 instances in the control. 9. It is of interest to note that the greatest number of cases of pulp stones and hypercementosis in both groups appeared between the ages of 41 and 50. It is of interest also to find that the greatest number of cases of hypercementosis appeared in the arthritic group

TABLE III

Tabulation of patients in both arthritic and control groups as to the number of cases of pulp stones and hypercementosis found in each age group

AGE GROUP	ARTHRITIC GROUP		CONTROL GROUP	
	Pulp stones	Hypercementosis	Pulp stones	Hypercementosis
13–21	2	0	1	1
22–30	2	1	5	1
31–40	3	1	6	1
41–50	6	6	8	1
51–60	2	3	3	2
61–65	0	0	0	0
Total.....	15	11	23	6

TABLE IV

Comparative study of control and arthritis group

	CONTROL	ARTHRITIS
No. of cases	48	46
Average age	40	40
No. of males	16	24
No. of females	32	22
No. of cases with pulp stones	23	15
(Percentage)	48	32
Average number of such teeth with pulp stones	2.8	2.6
No. of cases with hypercementosis	6	11
(Percentage)	12.5	24
Average number of such teeth with hypercementosis	2.3	3.9

between the ages of 41 and 50 and the largest number of cases of pulp stones appeared in the control group between the ages of 41 and 50 (Table III).

SUMMARY

1. The control cases showed a slightly higher incidence of pulp stones; 48 per cent as compared to 32 per cent. The average number

of teeth in positive cases was practically identical in both groups; 2.8 for the control group as compared with 2.6 for the arthritic group (Table IV).

2. The arthritic cases showed a higher incidence of hypercementosis; 24 per cent as compared to 12.5 per cent. The average number of such teeth in positive cases was 2.3 for the control group as compared with 3.9 for the arthritic series. The difference between these groups is probably due to the 1 unusual case in which all the teeth (22) were affected with hypercementosis. The paucity of material might also cause a greater difference in this group. Actually, the difference in percentage represents 5 additional cases in the arthritic group (Table IV).

3. The difference in incidence of pulp stones between the arthritic and control groups is so slight as to be insignificant.

4. The differences in hypercementosis between both series are probably not significant because of paucity of cases. This will have to be determined by further study.

CONCLUSIONS

1) From study of the available cases there seems to be no relationship between either pulp stones or hypercementosis and arthritis.

The author wishes to express his appreciation to Drs. Darlington, Segenreich and S. C. Miller of New York University, and Dr. David Tanchester of Montefiore Hospital for their valuable suggestions in the preparation of the paper.

The author wishes to acknowledge the assistance of Dr. Benjamin Seidler Research Fellow, Periodontia Department, New York University College of Dentistry in the preparation of the statistical data.

CALCIUM DEPOSITION AND ENAMEL HYPOPLASIA[1]

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In a previous publication (1) the author described hyperplasia of the stratum intermedium in a case of severe rickets in a human. At that time the observation (*fig. 1*) was not explained.

When a tissue becomes hypertrophied in the course of a certain pathologic condition it is probable that the involved tissue is attempting to compensate for some failure of its own function. The failure in this instance (poor calcification) is caused by conditions outside the stratum intermedium but the stratum appears to control enamel calcification. *Fig. 2* shows a human tooth germ following fluorin injections. Numerous globules of colloidal calcium can be seen outside the stratum intermedium. These globules cannot be products of the ameloblasts and are probably produced by the stratum intermedium. The stratum intermedium is found universally in the animal kingdom wherever enamel is formed. The observations illustrated in *figs. 1* and *2* suggest that colloidal calcium is prepared in the stratum intermedium and carried by the ameloblasts to the organic matrix of the prisms. The organic matrix is formed by the ameloblasts.

Formerly, the calcification of enamel and dentin was considered in terms of calcospherites. We conjectured that in normal calcification the globules fused and produced homogenous calcified material. In rachitic individuals we find the globules and uncalcified matrix, where interglobular areas are left between the isolated globules. If the calcospherite were the normal unit of colloidal calcium in the process of calcification, we should expect them to be uniform in size. One can scarcely find two globules of the same size in rachitic dentin. Those globules shown in *fig. 2* are also of various sizes. Moreover, globules of colloidal calcium are found only in tooth germs with disturbed

[1] Received for publication May 10, 1941. Revised by author October 6, 1941.

calcification, never in normal tooth germs. In an early stage of enamel formation (*fig. 3*) streams of colloidal calcium are seen going through two different groups of ameloblasts and in one place there seems to be a connection between the stream and the stratum intermedium.

It seems probable that the colloidal calcium prepared outside the ameloblasts flows in continuous streams through the ameloblasts to the organic matrix of the enamel rods. If disturbances occur in the

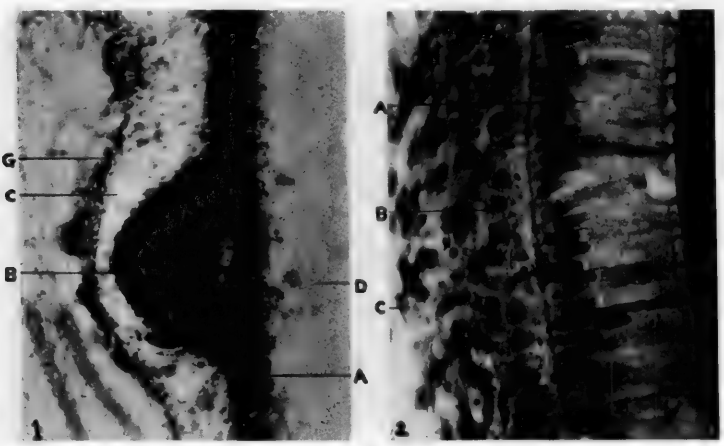

FIG. 1. Rachitic human tooth germ. a. Ameloblasts, b. Stratum intermedium (hypertrophied), c. Stellate reticulum, d. Enamel, g. Outer enamel epithelium.

FIG. 2. First molar of a flourine injected individual. a. Ameloblasts, b. Stratum intermedium, with globuli of colloidal calcium of different sizes, c. Stellate reticulum. (Courtesy of I. Schour.)

flow, calcium particles of various sizes become isolated and form globules. The finding of globules is a symptom of disturbance in the normal process of calcification. This hypothesis does not contradict the theory of rythmic apposition and calcification of Schour (2). The flow can be interrupted for a time and then started again without any part of the fluid being isolated.

In many cases of enamel hypoplasia, colloidal calcium is found in degenerating ameloblasts. If the corresponding layers of dentin show poor calcification it can be assumed that the calcium passing through the ameloblasts has not been taken up by the organic matrix of the

enamel. The matrix apparently is unprepared to combine with the calcium salts (rachitic condition). The calcium stagnates and remains in the ameloblasts and may produce a degeneration of those cells. In such instances the disturbance of calcium metabolism is the primary factor and the degeneration of ameloblasts and enamel hypoplasia are found without any signs of disturbance in calcification

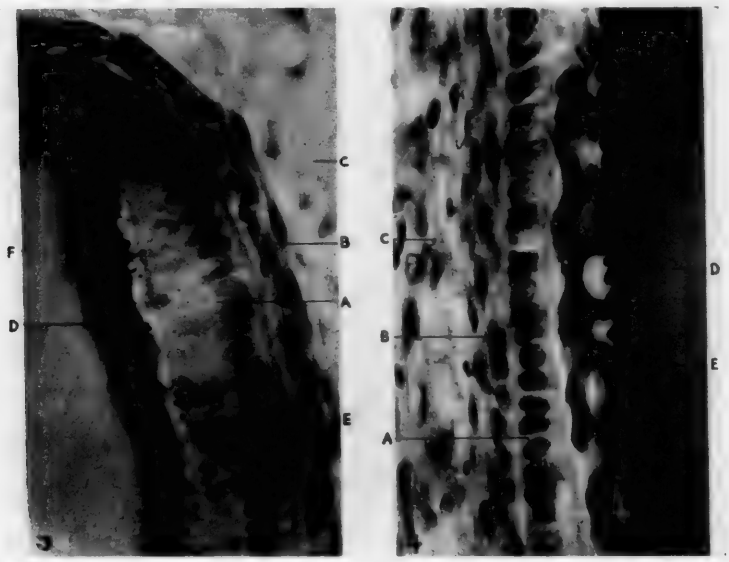

FIG. 3. Tooth germ of a human being. a. Ameloblast, b. Stratum intermedium, c. Reticulum, d. Enamel, f. Dentin, e. Continuous flow of colloidal calcium through ameloblast. Note isolated globuli of colloidal calcium in the ameloblastic area.

FIG. 4. Human tooth germ. a. Ameloblasts, b. Stratum intermedium, c. Stellate reticulum, d. Enamel, e. Large piece of colloidal calcium between enamel and ameloblast. (Courtesy M. K. Hine.)

of dentin. There is, apparently, a primary degeneration of the ameloblasts causing the enamel hypoplasia.

In cases of disturbed calcium metabolism during enamel formation particles of colloidal calcium are found, often, at different places in the neighborhood of the formed enamel. Either the formed enamel matrix did not take up the calcium or enamel matrix was not formed and the calcium could find no place to deposit. *Fig. 4* shows such a condi-

tion. A large irregular mass of colloidal calcium lies between the enamel and ameloblasts. The patient with this condition died at 3 months with lobar pneumonia. No explanation is offered for this finding.

The author wishes to express his appreciation to Drs. Isaac Schour and M. K. Hine of the University of Illinois for the material illustrated in figs. 2 and 4.

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ODONTOBLASTS IN THE DENTINAL TUBULI[1]

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In studying acute inflammation of the pulp, the presence of leukocytes in the dental tubuli was observed.[2] This peculiar phenomenon was explained as a migration of leukocytes from the pulp into the tubuli due to some chemotactic influence in the dentin. In these and other specimens some other peculiar cellular elements, different from leukocytes, were seen in some dentinal tubuli, these occurring frequently in well-circumscribed areas. The identification of these structures caused considerable difficulty, but was accomplished by experimental investigation.

One of the first specimens in which these cells in the dentinal tubuli were observed was a lower premolar. In a well-circumscribed area of the pulp (*fig. 1*) the odontoblasts are missing. Corresponding to this region, elongated bodies are seen in tubuli deep within the calcified dentin. The pulp tissue in this area is somewhat fibrous and edematous and a few cells are present where formerly there were odontoblasts. On the right side of the specimen there is a wide layer of secondary dentin, formed in reaction to a carious lesion. The pulp has shrunken to some degree and numerous wandering cells appear in this area.

At a higher magnification, the dark, elongated bodies in the dentinal tubuli (*fig. 2*), are observed to stain similarly to the chromatin of cell nuclei. Two bodies are found at the border of the calcified and uncalcified dentin; others occur in the predentin, or partly in the pulp.

The pulp of the extracted tooth illustrated in *fig. 3* appears normal. Several small pulp stones are present, but there are no signs of inflam-

[1] Read at the 19th General Meeting of the International Association for Dental Research, St. Louis, Mo., March 15 and 16, 1941 (*J. D. Res.*, 20: 260, 1941). (Received for publication June 27, 1941).

[2] Orban, B., J. A. D. A., 27: 239, 1940.

mation. On both sides of the pulp canal there is a limited area in which the odontoblasts are missing (a and b) and cellular bodies appear in dentinal tubuli as seen in *figs. 1* and *2*. A higher magnification (*fig. 4*) shows region a. In the pulp tissue adjoining this area vacuoles appear and the intercellular spaces seem to be enlarged. This picture is similar to that found in reticular atrophy of the pulp. Some of the cellular bodies are deep in the calcified dentin, while others are partly in the pulp and partly in the dentin, giving a club-like appearance.

In one instance (*fig. 5*) there occurred, not only a very considerable cell invasion into the dentinal tubuli, but also capillary hemorrhage along the wall of the dentin, chiefly between the odontoblasts.

DISCUSSION

The first observance of these bodies was noted at the time of a study on the migration of leukocytes into the dentinal tubuli. These bodies in the present investigation (*figs. 1* to *5*) are quite different from leukocytes. They consist only of one elongated nucleus; no chromatin bridges connect different nuclear lobes, as in the case of leukocytes. No granules are present in the cytoplasm, as in leukocytes, especially of the eosinophilic type. The differences indicate that these elements are non-granular, mononucleated, and they suggest cells of the lymphocytic type. However, the migration of these elements into the dentinal tubuli was very doubtful and there was not enough proof for this supposition. A second possibility to be considered was that these cellular elements might be odontoblasts. This was difficult to imagine because, as can be seen in *fig. 2*, normal dentinal tubuli are present pulpward from these elements. These normal dentinal tubuli could not have developed if the odontoblasts had been trapped there during the formation of the dentin. They must have entered after the formation of the tubuli, a hypothesis also suggested by the elongated shape of the bodies.

In repeated observation of these findings it was deduced that these cells entered the dentinal tubuli by some mechanical means. Two factors at the time of extraction could produce trauma and either might be responsible for these lesions in the pulp. One factor is, that in an effort to have well fixed and prepared specimen, it has been our practice, immediately after extraction, to grind off with a diamond

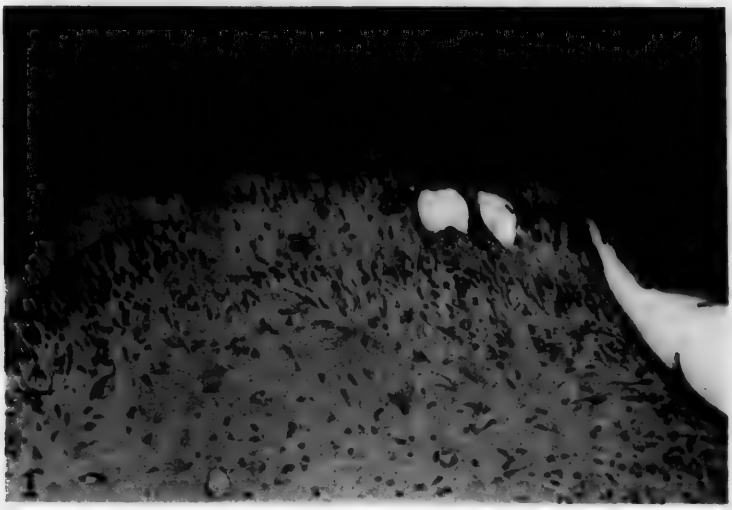

FIG. 1. Human pulp. In a well circumscribed area (a) odontoblasts are missing. Corresponding to this region cellular elements are found in dentinal tubuli (b). Secondary dentin (c).

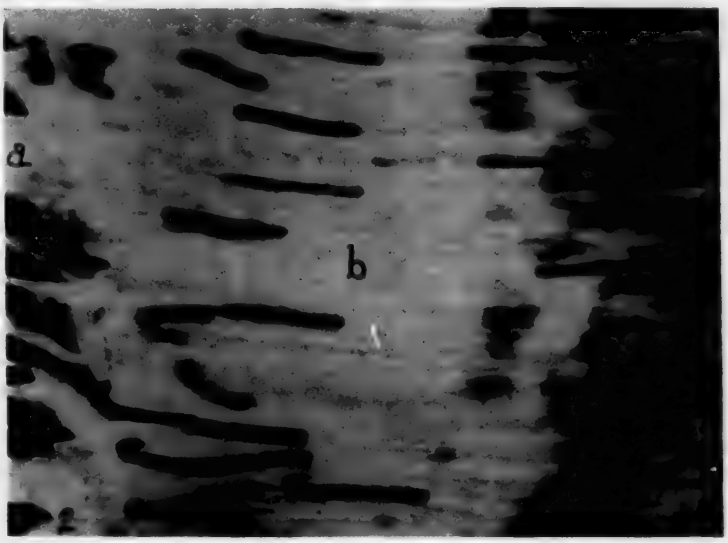

FIG. 2. Higher magnification of region (b) in *fig. 1*. Cellular structures in dentinal tubuli. (a) pulp, (b) uncalcified dentin, (c) calcified dentin.

FIG. 3. Human tooth. Pulp stones in otherwise normal pulp. At (a) and (b) the odontoblasts are missing, and at same region, cells are found in dentin. Corresponding to these areas there is a break on surface of tooth (c).

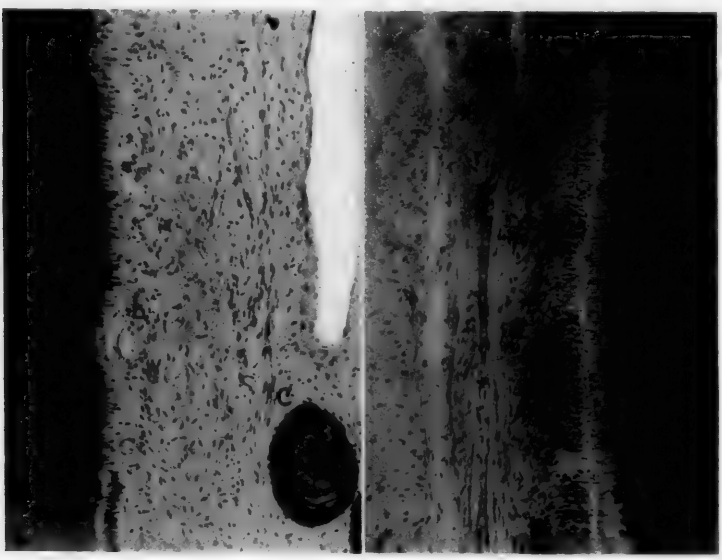

FIG. 4. Higher magnification of area (a) from *fig. 3*. Large number of cells in dentinal tubuli (a). At place where odontoblasts were, edema and vacuoles appear (b). (c) pulp stone.

FIG. 5. Human pulp. At region of former odontoblasts hemorrhage (a) is seen. Corresponding to this area there was injury on tooth surface. Cells (b) in dentinal tubuli.

disc, under a continuous stream of water, as much enamel and dentin as possible from the tooth without exposing the pulp. It was first believed that the grinding might be responsible for the pulp changes but this was soon disproved. The other factor which might have produced the trauma was the pressure of the beaks of the forceps used in extraction. In several cases the following experiment was carried out: Some teeth were extracted according to the regular practice. The forceps were applied with considerable force labio-lingually. Other teeth were extracted with the forceps applied very carefully, holding the tooth mesio-distally. In this way a pressure was applied to the root surface in some cases, resulting in a break in the cementum and dentin where forceps cut into the tooth, while others were extracted without any surface injury. It was demonstrated that the injury caused by the beaks of the forceps was responsible for the entrance of cellular structures into the dentinal tubuli.

The previously described changes in the pulp, where cells were found in the dentinal tubuli, could be observed regularly in those cases where a considerable pressure had to be used with the forceps during extraction, and the root surface was broken (*fig. 3*). This result could be obtained quite regularly, especially in young individuals, and if the teeth had neither fillings nor extensive caries.

CONCLUSION

From these results the conclusion is reached that, during extraction, odontoblasts become situated in the dentinal tubuli at the spot where the beaks of the forceps act on the surface of the root. What ultimately causes the odontoblasts to enter the tubuli is still a question, but it is possible that the processes of the odontoblasts, the dentinal fibers, shrink, due to the surface injury and pull the corresponding odontoblasts into the tubuli; or there may be a slight compression of the dentin and pulp, thus causing some sucking or pumping action upon the odontoblasts. Whether or not other dental operations, such as cavity preparations, grinding of a tooth for a crown, pounding a gold foil, etc., could produce similar or different injuries in the pulp, must be determined in future investigations.

FURTHER STUDIES IN MINERAL METABOLISM OF HUMAN TEETH BY THE USE OF RADIOACTIVE PHOSPHORUS[1]

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By the use of radioactive phosphorus it has been demonstrated that an exchange of mineral substances takes place in the enamel of a normal adult tooth (1, 2, 3). In a previous report (3) we have shown that radioactive phosphorus appears in the saliva within 24 hours following intravenous injection and that the intake of phosphorus by the enamel of a normal adult tooth is much greater through the dentin than through the saliva. Even following a traumatic injury to the pulp a day or so before the administration of the radioactive element, we found that the amount of phosphorus entering the enamel from the saliva was negligible when compared with the intake through the dentin. Therefore we concluded that the cemento-dentinal junction served as a major pathway for the supply of the tooth.

The purpose of this paper is to report in more detail the mineral intake of human teeth from the saliva and especially to investigate the influence that dental caries may have upon this intake. As a tracer substance, radioactive phosphorus was used. In this investigation it was essential that only the saliva contain radioactive phosphorus, and that the entrance of radioactive phosphorus into the bloodstream be inhibited.

Sodium phosphate containing radioactive phosphorus with an activity of about 1.5 m Curies was dissolved in 10 to 12 cc. of water and used as a mouth rinse in order that the radioactive element could be brought into intimate contact with the exposed surfaces of the teeth. After the patient had rinsed the mouth with this solution for a few minutes, 4 teeth were extracted, one of which showed no indication of caries, the other 3 having definite carious lesions. Following extrac-

[1] (Received for publication June 15, 1941.)

tion each tooth was divided at the cemento-enamel junction into the root and crown portions, the dentin of the crown being separated from the enamel by use of a round bur. The enamel which remained in the form of a shell was pulverized for the measurement of its radioactivity.

The results of the experiment are given in Table I. In this table the activities for the same weight of tissue are shown in arbitrary numbers. The first 2 rows show corresponding teeth, right and left lower second molars. The right second molar, shown in the first line of the table, is normal while the other contained an advanced carious lesion. Of the teeth in the third and fourth lines (right and left mandibular third molars), the right molar contained the larger cavity. It follows from the table that the amount of phosphorus intake by the dentin of a caries-free tooth is too small to be determined. In the carious tooth

TABLE I

		ENAMEL	CROWN DENTIN
$\overline{7}\vert$	Caries-free	.0006	.000
$\vert\overline{7}$	Carious	.042	1.47
$\overline{8}\vert$	Carious	.060	1.12
$\vert\overline{8}$	Carious	.10	1.16

where the dentin is directly exposed, the intake of radioactive phosphorus is more than one thousand times greater than in the caries-free tooth. In the normal tooth, the intake of phosphorus by the enamel is about one hundred times less than that of the carious teeth. This suggests the possibility that the outer surface of the enamel does not receive much of its mineral content from the saliva. However, when the dentin is exposed to the fluids of the mouth, substances are more readily absorbed, which in turn permits the enamel to absorb these substances from the dentin.

In a previous publication we investigated the entrance of a substance into the tooth from the bloodstream through the pulp, the cemento-dentinal junction, and the saliva. If a substance is administered by mouth, a part of it may enter a tooth directly from the saliva while the remainder enters the tooth through the pulp or cemento-dentinal junction following its absorption into the bloodstream. It is of interest to compare the amount of the tagged element absorbed directly from the saliva with the amount absorbed from the bloodstream.

An aqueous solution of sodium phosphate with radioactive phosphorus of an activity of 2 m Curies was administered to a patient by mouth. Some of the teeth were removed in 24 hours while the others were not extracted until 4 days later. A patient was selected for the study who required the removal of all of the remaining teeth. In this way teeth with a variety of clinical conditions could be obtained while the factors of dosage, degree of absorption from the gastrointestinal tract, etc. remained constant. The supporting structure of all the teeth had been involved to varying degrees by periodontal disease. Some of the teeth were caries-free; one had a very small early cavity, while others contained extensive areas of decay. Some of the carious teeth had previously had their pulps removed and the pulp-canals filled.

The contents of radioactive phosphorus for the same amount of weight (densities of radioactive phosphorus) for different parts of the tooth are shown in Table II. The dentin was divided into 2 parts, i.e., crown and root dentin, along the cemento-enamel junction. The amounts given for the cementum are not considered accurate since the cementum was separated from the dentin by grinding away the outer layer of the root of each tooth. Obviously this cementum is mixed with some root dentin.

In the first 4 lines of Table II, the results for normal teeth without caries are given. The table shows that the density of radioactive phosphorus in the enamel is about 14 per cent of that found in the dentin. The above data compare favorably with those obtained in our former study (3) where we found in normal teeth of dogs a difference of approximately 19 per cent. This result indicates that for normal teeth without caries, the greatest supply of the enamel takes place from the inside of the tooth, even when the substance is administered by mouth. The results of our measurements of the enamel and the dentin of normal teeth are certainly not affected by the fact that periodontal disease was present because this condition does not influence the supply of the tooth through the pulp.

In lines 5 and 6, the results are shown for carious teeth with normal pulps. In these cases the enamel shows a greater density of radioactive phosphorus than in teeth without caries, and the crown dentin shows a greater density than the root dentin. This confirms our

opinion that in the case of caries an appreciable intake from the saliva takes place.

In the last 3 lines the results are shown for carious teeth with filled pulp canals. The teeth in lines 7 and 8 had the largest cavities. In both of these teeth, the larger part of the crown was missing. On the other hand the tooth in line 9 had only a small cavity. The teeth in lines 7 and 8 show the largest intake from the saliva of radioactive phosphorus by the enamel and the crown dentin. The tooth in line 9,

TABLE II

ROW	TOOTH	ENAMEL	CROWN DENTIN	ROOT DENTIN	CEMENTUM
Normal teeth without caries					
1	$\overline{\lvert 1}$	.018	.18	.15	.20
2	$\overline{2\rvert}$	.023	.16	.14	.038
3	$\overline{\lvert 3}$	.019	.10	.08	.069
4	$\overline{1\rvert}$		.11	.10	.094
Carious teeth with vital pulps					
5	$\overline{\lvert 7}$	.037	.11	.064	.092
6	$\overline{\lvert 4}$	.067	.11	.073	.093
Carious teeth with filled root-canals					
7	$\overline{4\rvert}$	.141	.40	.001	.113
8	$\overline{7\rvert}$	.124	.89	.053	.065
Tooth with filled root-canal and small caries lesion					
9	$\overline{\lvert 5}$	.0134	.003	.0034	.053

which had only a small carious area, shows a much smaller intake of radioactive phosphorus by the enamel, and also in agreement with this, practically no difference in the densities of radioactive phosphorus in the root and crown dentin.

When these results are compared with the measurements of the previous study (3), we find that the cementum of teeth with periodontitis shows a lower density of radioactive phosphorus when related to the value of the dentin of a normal tooth. When the dentin was not exposed to the saliva we found less radioactive substance in the dentin of pulpless teeth which had been involved with periodontal disease

than that with a healthy periodontal membrane. In comparing the density in the crown and root dentin of the tooth in row 9 and the density of the root dentin of the tooth in row 7 with the density of normal teeth, we see that the values given for carious teeth with filled pulp canals is only 1 to 2 per cent of that given for normal teeth. In earlier experiments the difference of the densities between the dentin of pulpless teeth and teeth with a vital pulp was found to be 10 per cent.

The difference between the results of this study and those of the former study is probably due to the periodontal disease which decreases the intake through the cementum. However, the influence of periodontal disease on the metabolism of the tooth needs further investigation.

SUMMARY

1. It has been shown that the enamel protects the dentin from an intake of mineral substances (phosphorus) from the saliva. When part of the protecting enamel is missing, as is the case in carious teeth, the dentin takes up substances directly from the saliva.

2. The intake of minerals from the saliva into the enamel of a caries-free tooth is very small. This intake becomes about one hundred times larger when part of the enamel is missing. Therefore, an appreciable intake of mineral substances by the enamel from the saliva takes place only if the substances can enter from the inner surface of the enamel.

3. In substances administered by mouth, the intake of minerals by the enamel of a normal tooth takes place to the greatest extent through pulp and dentin, while the direct intake of the substance from the outer surface of the enamel is comparably small.

4. Periodontitis seems to decrease the exchange of mineral substances through the cementum. In pulpless teeth, periodontitis also decreases the exchange of minerals in the dentin. These results indicate that the exchange of minerals through the periodontal membrane decreases as a result of periodontitis.

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THE PREVALENCE OF TOOTH ROOT EXPOSURE, AND THE RELATION OF THE EXTENT OF SUCH EXPOSURE TO THE DEGREE OF ABRASION IN DIFFERENT AGE CLASSES[1]

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This study is based on 200 individuals examined in the dental clinic at Ohio State University. Most of these were clinic patients, but a small number of dental students and members of the clinic staff were included. The group was divided into 4 age classes as follows: 20–29, 30–39, 40–49 and 50–59. An attempt was made to get a 60–69 year class, but an insufficient number of people with natural teeth were available to permit its inclusion in this report. An equal number of males and females were examined in every age group, thus the 50 individuals making up each of the age classes consisted of 25 males and 25 females.

The data were collected by 2 dental graduates working half time each in such a manner as to cover the clinic waiting room at all times. After the data had been collected, a check was made on the number of patients in every age class who had been examined by each observer. This showed a fairly equal division of the work. The 2 observers were checked against each other by having them examine several of the same patients. One observer (B) was consistently more conservative in his grading of the degree of abrasion than was the other (V). However, the fairly equal division of patients between them minimized the personal difference in observation. With this number of patients, however, all data are comparative rather than absolute.

The information concerning each patient was gathered on a mimeographed form, a photograph of a sample copy of which is included in

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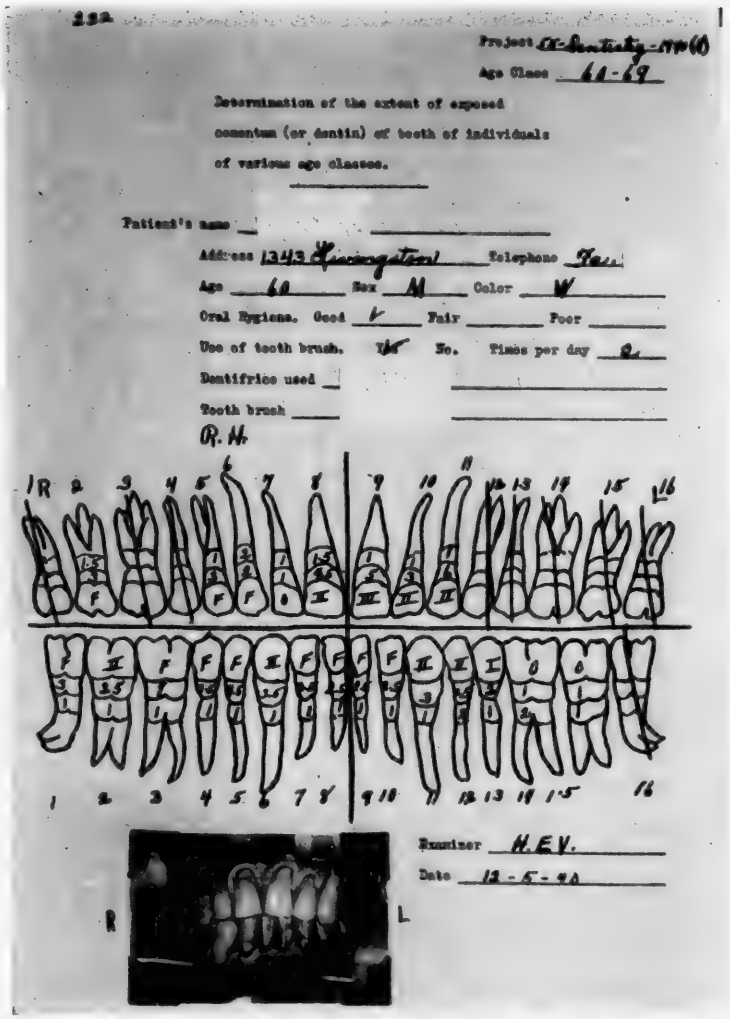

SAMPLE DATA SHEET USED IN GATHERING THE INFORMATION FOR THIS REPORT

The figures at the apical ends of the teeth are tooth numbers used in the tabulations for assembling the data. The figure on the tooth diagram nearest the root end of the tooth indicates the depth of the gingival crevice (data not treated of in this report); the figure adjacent to this shows the millimeters of cervical exposure; while the symbol on the crown of the tooth indicates the degree of abrasion. (Where F occurs, it indicates the presence of a cervical filling.)

this report. The measurement of the cervical tooth exposure was a linear one, made at the mid-labial (or mid-buccal) of each tooth excepting the molars, where the midline of the mesial root was used. The measuring was done with Box periodontal probes, numbers 3 and 4. These probes are graduated in millimeters, and, with the exception of the handles, are of sterling silver, hence easily sterilized by flaming (*fig. 1*).

The loss of tooth structure (cementum, dentin, or both) in areas of exposure, which was in all cases an apparently polished cut, was determined on the basis of the depth of the cut at the same place that the linear measure of exposure was made. Four degrees, or grades, of what

FIG. 1. Box periodontal probes, right and left, used to measure vertical length o cervical exposure and depth of abrasion.

was judged to be abrasion were recognized and classified on the following basis:

Visible, but with depth of not to exceed 0.5 m.m.	Grade I
Depth of over 0.5 m.m., but not exceeding 1.0 m.m.	Grade II
Depth of over 1.0 m.m., but not exceeding 1.5 m.m.	Grade III
Depth exceeding 1.5 m.m.	Grade IV

RELATION OF CERVICAL EXPOSURE TO AGE AND SEX

The first question to which an answer was attempted was, "How does cervical exposure vary with age and sex?"

In order to arrive at an arrangement of data which would lend itself to visual presentation, frequency tables were made which showed the number of times that exposure of different lengths (and absence of exposure) occurred in each of the 32 teeth of various age classes. In order to visualize the material of these tables, bar graphs were con-

structed for each to show (1) the actual number of teeth examined in each tooth location, (2) and the number of teeth in each tooth location which (a) were free from exposure, had (b) 0.5 m.m. exposure, (c) 1.0 m.m. exposure, (d) 1.5 m.m. exposure, (e) 2.0 m.m. exposure, (f) 2.5 m.m. exposure, (g) 3.0 m.m. exposure, (h) 3.5 m.m. exposure, (i) 4.0 m.m. exposure, (j) 4.5 m.m. exposure and (k) over 4.5 m.m. ex-

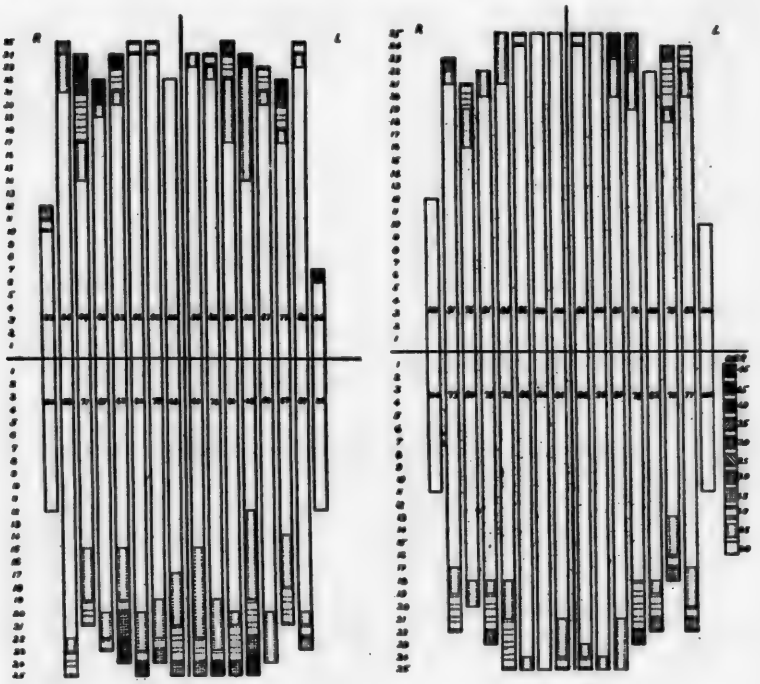

FIG. 2A FIG. 2B

FIG. 2. Number of teeth in each tooth class showing different degrees of cervical exposure in males (A) and females (B) of 20-29 years.

posure. These bar graphs for males and females of the various age classes are illustrated in *figs. 2, 3, 4,* and *5*.

Since 25 male and 25 female patients were examined in each age class, the highest possible number of teeth in each tooth location is 25. Less than that number is due to missing teeth. This condition is particularly evident in the 4 molar regions of the age classes subsequent

to the 20–29 year group. The numbers placed in each of the bars are the percentages of the teeth in the various tooth locations which were free from cervical exposure. Exposures of different intensities in various tooth locations are shown by filling in the bars on the basis of the legend attached to the graphs of the teeth of female patients. The

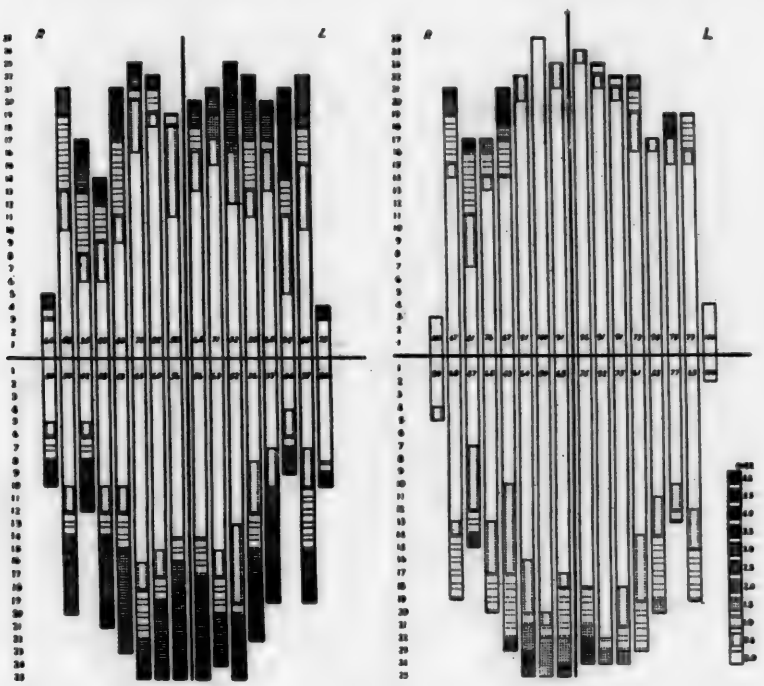

FIG. 3A FIG. 3B

FIG. 3. Number of teeth in each tooth class showing different degrees of cervical exposure in males (A) and females (B) of 30–39 years.

bars above the heavy cross line represent upper teeth, below the cross line, lower teeth. The heavy vertical line denotes the midline. R is the right side and L the left side of the dentition. Vertical figures on the left permit a determination of the number of teeth found in each exposure class.

A study of these graphs brings out several points: 1. Exposure in-

creased in both frequency and linear dimension with age. While the 20–29 age class is not at all free from exposure, that which was found was largely of the 0.5 m.m. type, with some instances of 1.0 m.m., but very little in excess of that. 2. The most pronounced increase of exposure was from the 20–29 to the 30–39 age class and this was especially true of males. From there on, the increase of amount and

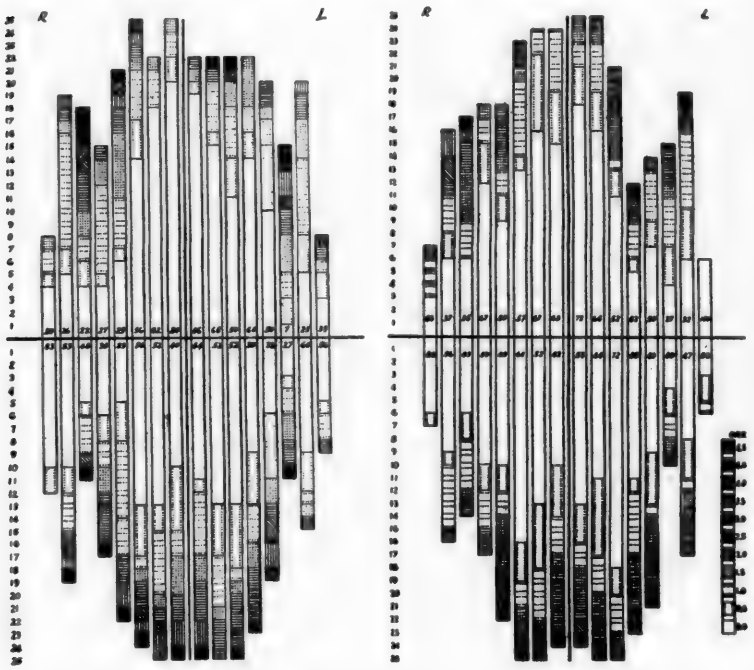

FIG. 4A FIG. 4B

FIG. 4. Number of teeth in each tooth class showing different degrees of cervical exposure in males (A) and females (B) of 40–49 years.

intensity was not so pronounced. 3. A very interesting finding was the variation in males and females of the same age class. It is clearly apparent in the 20–29 and 30–39 age classes that females showed less frequent occurrence and a lesser linear dimension of exposure than did the males of the same age. The 40–49 and 50–59 age classes show similar sex differences, but to a lesser degree.

If we consider only the average percentage of teeth that were free from any exposure in each tooth location of the various age classes of

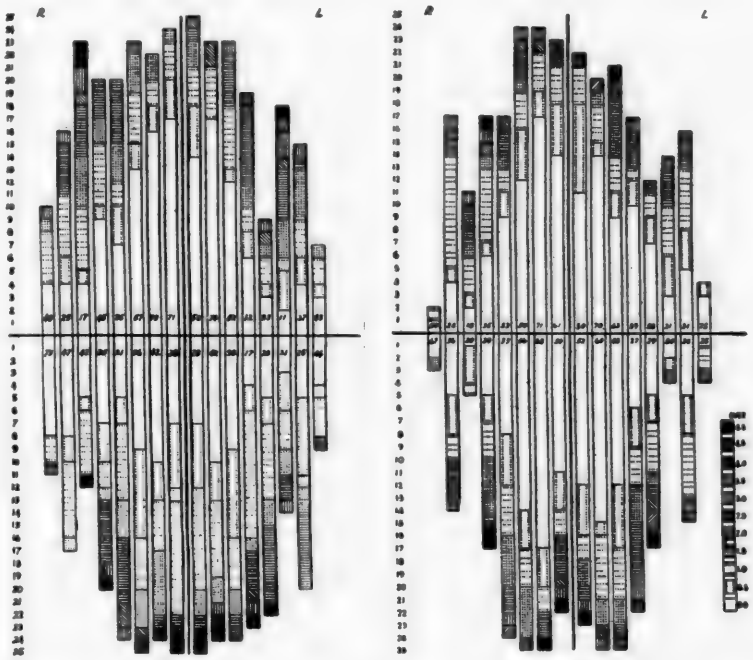

FIG. 5A FIG. 5B

FIG. 5. Number of teeth in each tooth class showing different degrees of cervical exposure in males (A) and females (B) of 50–59 years.

TABLE I

Average percentage of all teeth free from any cervical exposure

	20–29 YEARS	30–39 YEARS	40–49 YEARS	50–59 YEARS
Males	80.6%	53.3%	47.1%	39.2%
Females	88.3%	77.2%	53.1%	45.4%
Both	84.5%	65.3%	50.1%	42.3%

males and females, the following figures (Table I) bear out the more general visual findings stated under 1–3 above.

RELATION OF ABRASION TO VARIOUS AGE CLASSES

With this point and most of the subsequent ones, no attempt has been made to deal with the male and female patients separately.

Having surveyed the patients on the basis of the cervical exposure found to be present, the next concern was the condition of abrasion. All the individuals of each age class were gone over for the number of persons having (1) any tooth showing any degree of abrasion, (2) any tooth showing abrasion of greater depth than 0.5 m.m., (3) any tooth showing abrasion deeper than 1.0 m.m., (4) any tooth showing abrasion in excess of 1.5 m.m., and as the complementary condition, (5) the number of persons showing no abrasion of any type on any tooth. These data are shown graphically in *fig. 6*.

The patients examined showed that some degree of abrasion was present in 42 per cent of the youngest age class (20–29) and that in persons of middle age, 76 per cent were involved. Abrasion in excess of 0.5 m.m. in depth included only 4 per cent of the 20–29 year group, but increased to 14 per cent of persons 30–39 years of age, reaching a maximum of 30 per cent of persons 40–49 years old. The deeper than 1.0 m.m. abrasion involved much smaller percents of persons in the different age classes, but tended to show increased incidence with advance in age. The greater loss of teeth from the mouths of the 50–59 year class, and the presence in that group of one unusual individual with no exposure, are probably responsible for what appears to be a falling off from the 40–49 age class figure.

It should be noted here that all the abrasion, which could be expected with the amount of exposure found to be present in these patients, has probably not actually occurred. Abrasion is the result of toothbrush plus an abrasive dentifrice action. Only persons attempting to maintain constant good oral hygiene, and using a cross brushing technic on cervical exposures, would produce a maximum abrasion condition for the time period involved. The patients examined showed 75 to be of fair oral hygiene, 47 of poor oral hygiene, 67 of good hygiene and 11 not classified. This would mean that the abrasion figures would probably be less than in a group all of whom were making a serious effort to keep their teeth clean. The above consideration should be borne in mind during the subsequent dis-

cussion of the occurrence of an exposure judged to be critical in the relation of exposure to abrasion and the possible extent of abrasion based on the occurrence of this critical exposure.

RELATION BETWEEN CERVICAL EXPOSURE AND ABRASION

With conditions in regard to the prevalence, distribution and intensity of cervical exposure and abrasion demonstrated, the question arose as to how much cervical exposure is necessary to have abrasion occur when good oral hygiene is maintained with a toothbrush and an abrasive dentifrice.

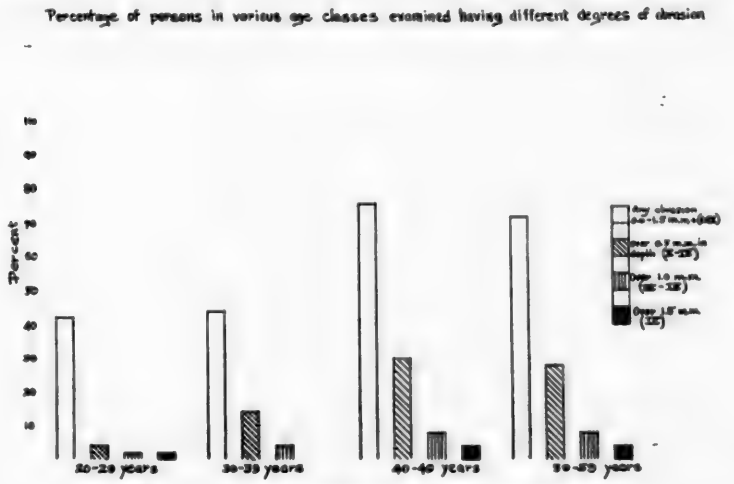

FIG. 6. Abrasion conditions in different age classes

This question was attacked on the basis that (1) right-handed individuals do a superior job of tooth cleaning on the left side of the mouth (the reverse is true of persons using the left hand and the data were so selected), (2) that our observations indicated the greatest abrasion in the upper canine and premolar area, and (3) that some time must be allowed to accomplish abrasion after cervical exposure occurs. Data were used only from those patients who brushed their teeth, were classified as showing good oral hygiene, and were included in the 30–60 age classes. There were 41 such patients.

A consideration of the relation of cervical exposure and abrasion in

the upper left canine, first and second premolar had to be based on a small number of teeth, since only 41 were available. Because of this and the desire to see whether differing numbers of teeth would support the findings on these selected ones, frequency tables were made for (1) the upper and lower left canine, first and second premolar (107 teeth); (2) all the upper teeth (193 teeth); and (3) all the teeth (435 teeth). The data from these tables are arranged in graphic form in *figs. 7* and *8*.

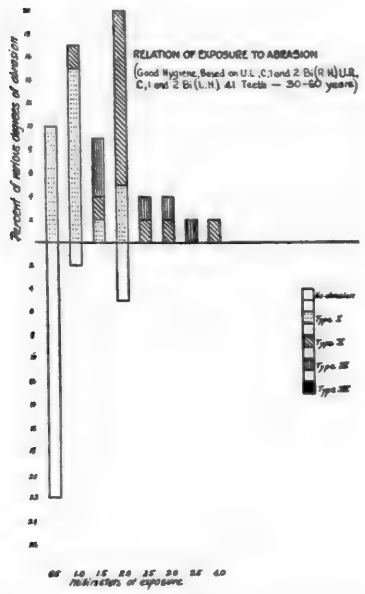

FIG. 7A

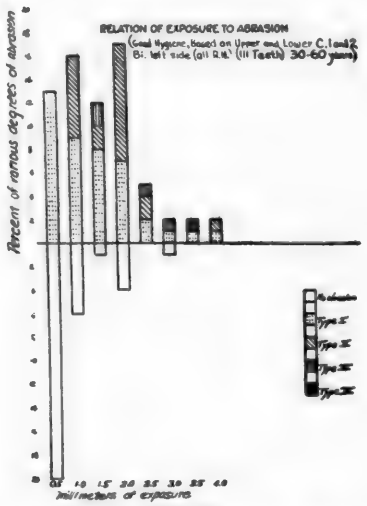

FIG. 7B

FIG. 7. The relation of exposure to abrasion under conditions of good oral hygiene

The part of the bars reaching below the zero lines in *figs. 7* and *8*, (as well as *9* and *10*) represent that part of the various exposures that occurred without the presence of any visible abrasion. While not a conventional arrangement, this does segregate that particular condition for each exposure classification. Observations indicate that the relation of exposure to abrasion, as shown by a small selected group of 41 teeth is quite consistent with the result from the larger groups, with the exception of the relation of the 1.0 exposure to abrasion. Here

the larger groups show that while this extent of exposure is more frequently associated with abrasion, which may even involve Grade II, there is a lesser chance that it may not be associated with abrasion.

Taken as a unit, *figs. 7* and *8* show that a 1.0 m.m. exposure could well be considered as critical in relation to abrasion and that exposure in excess of 1.0 m.m. showed a tendency to be associated in some degree with abrasion of Grade II. On the other hand, exposures of 0.5 m.m. were more likely to be associated with no abrasion than with abrasion.

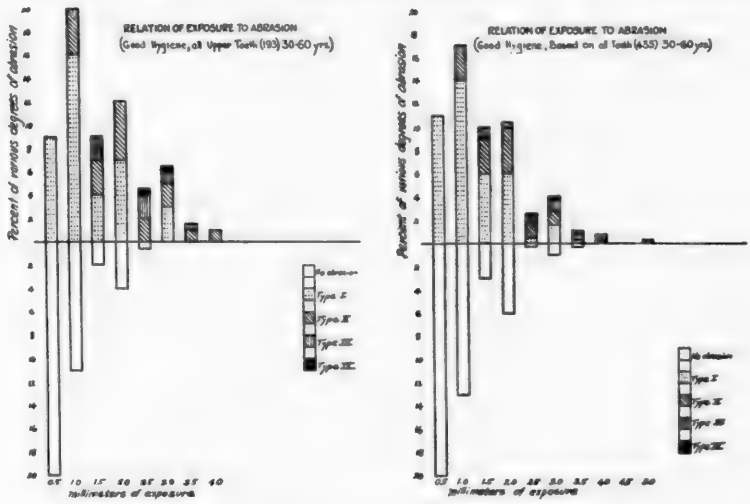
RELATION OF EXPOSURE TO ABRASION
(Good Hygiene, all Upper Teeth (193) 30-60 yrs.)
Percent of various degrees of abrasion
millimeters of exposure
RELATION OF EXPOSURE TO ABRASION
(Good Hygiene, Based on all Teeth (455) 30-60 yrs)
Percent of various degrees of abrasion
millimeters of exposure

FIG. 8A FIG. 8B

FIG. 8. The relation of exposure to abrasion under conditions of good oral hygiene

When they were associated with abrasion, it was never in excess of Grade I, (not over 0.5 m.m. in depth).

HAS ABRASION BEEN CONFUSED IN THIS STUDY WITH LOSS OF CERVICAL TOOTH STRUCTURE FROM OTHER CAUSES?

To answer this question the data on 43 patients who had been classified as having poor hygiene were segregated. Some of these patients said that they used a toothbrush, but all their mouths bore ample evidence that they neither used it much nor thoroughly. Frequency tables and graphs were made with the same tooth groupings as were employed in the "Good Hygiene" class. *Fig. 9* and *10* show

graphically the relation, or rather the lack of relation, between exposure and abrasion under this type of oral condition. A comparison

TABLE II

Showing areas of greatest abrasion occurrence, and relation of occurrence of abrasion to the condition of oral hygiene

TOOTH AREA	POOR HYGIENE GROUP (43 PATIENTS)		GOOD HYGIENE GROUP (41 PATIENTS)	
	No. teeth examined	Percent teeth with abrasion	No. teeth examined	Percent teeth with abrasion
All teeth	558	25	435	56
All upper teeth	236	28	193	63
Upper and lower left canine, 1st and 2nd premolar	103	44	107	70
Upper left canine, 1st and 2nd premolar	46	54	41	71

Arrows show direction of increase.

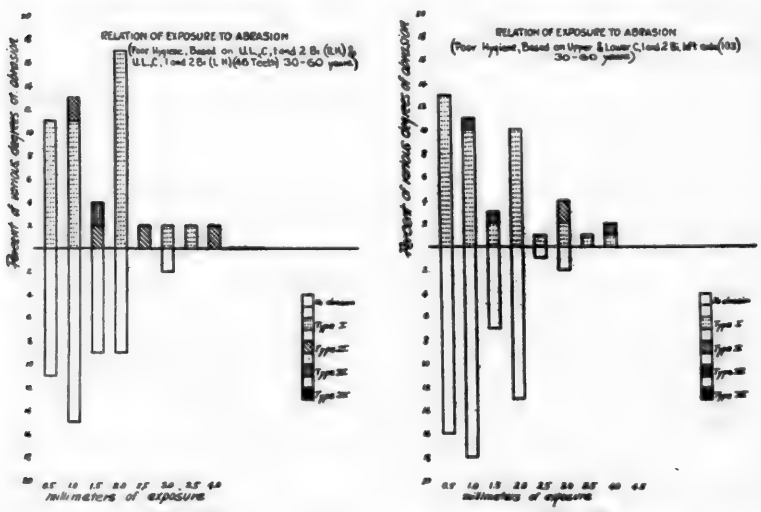

FIG. 9A FIG. 9B

FIG. 9. The relation of exposure to abrasion under conditions of poor oral hygiene.

of *figs. 7* and *8* on one hand, and *figs. 9* and *10* on the other, makes it seem evident that we have dealt essentially with the effect of the toothbrush and abrasive dentifrice on cervical exposure of the teeth.

Unlike the graphs pertaining to the good hygiene group, there is with "Poor Hygiene" no consistent tendency for exposure of 1.0 m.m., and greater, to be associated increasingly with more serious grades of abrasion. On the contrary, larger degrees of exposure showed as much, or more, tendency to be associated with no abrasion as they did to occur in company with the lowest grade (I) of abrasion. In none of these poor hygiene individuals did any abrasion greater than Grade II obtain, and the occurrence of this grade was very limited.

To demonstrate more specifically the relationship between the condition of oral hygiene and the extent of occurrence of cervical abrasion, and the degree of segregation of abrasion in certain tooth areas in poor as well as good hygiene conditions, the pertinent data are collected in Table II.

(In computing the percentages in Table II, no attempt was made to omit from the calculations teeth which had less than 1.0 m.m. of cervical exposure. This resulted in lower percentage figures in practically all instances and a lesser spread between the lowest and highest percentages given. These differences would be only a few percent in the poor hygiene group, but become much more marked in the good hygiene group. For example, on this latter basis, the percentage figures for the poor hygiene group would be 27 per cent, 27 per cent, 43 per cent and 55 per cent. In the good hygiene group, these percentages would be 64 per cent, 77 per cent, 85 per cent and 90 per cent.)

It will be noted from the above data that in poor, as well as good hygiene, the teeth on the left side of the mouth showed a markedly greater percent of cervical abrasion than was apparent from observation of both right and left sides together. In the poor oral hygiene group it was apparent that the teeth in the anterio-lateral areas were abraded to a markedly greater extent than those of the posterior areas and that the canine and premolar area opposite the hand which wielded the toothbrush showed definitely more abrasion than the similar area on the same side as the hand using the toothbrush. There was no significant variation in abrasion between the upper and lower teeth in the poor hygiene group when the entire arch was considered, but there was a higher percentage of abrasion in the upper left canine and premolar area than in the same area of the lowers when these were grouped by themselves.

In the good hygiene group there was, in general, about twice the percentage of abrasion in the comparable tooth groupings as was found under poor hygiene. Also, there was a greater percentage of abrasion in the upper teeth than in the lowers when the posterior teeth were included, but practically no difference in the upper and lower condition when the canine and premolar areas were considered apart from the others.

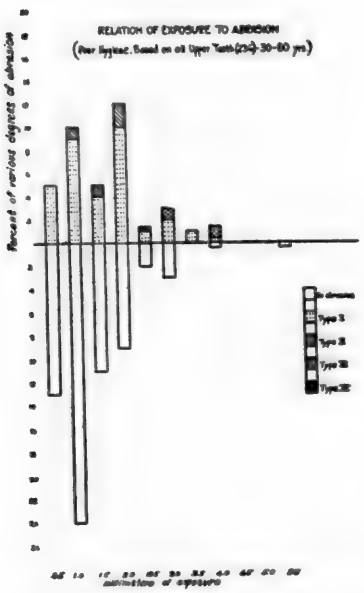

FIG. 10A

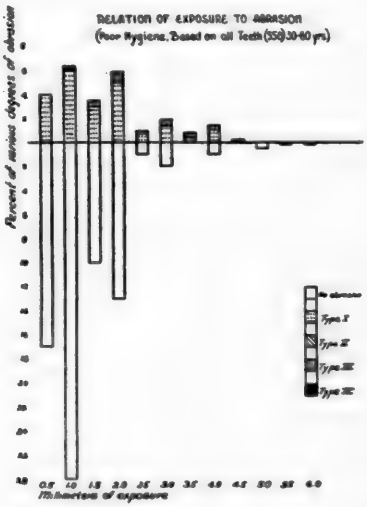

FIG. 10B

FIG. 10. The relation of exposure to abrasion under conditions of poor oral hygiene

POSSIBILITIES OF ABRASION IN DIFFERENT AGE CLASSES

The question to be considered here can be stated as follows: "Under conditions of good oral hygiene, maintained through the use of a toothbrush and a dentifrice of conventional abrasiveness, what percentage of persons in each age class have cervical exposures which, on the basis of this study, could be expected to be accompanied by abrasion?"

In the section of this report devoted to the relation of cervical exposure to abrasion, it was indicated that in the 41 cases of good hygiene

of patients 30–60 years old an exposure of 1.0 m.m. was the lowest amount which showed a distinct tendency to be associated with visible abrasion. When the total number of patients in all the various age classes were examined for the presence of any exposure of 1.0 m.m. or more, we found that in more than half (58 per cent) of the individuals of the 20–29 age class, there were exposures of 1.0 m.m. or more. In the 30–39 group the figure increased to 84 per cent and at 40–49 years a maximum of 96 per cent was reached. A slight falling off in the per-cent figure for the 50–59 age class (94 per cent) is due to 1 male individual who showed an unusual condition for the group. Of the 29 teeth

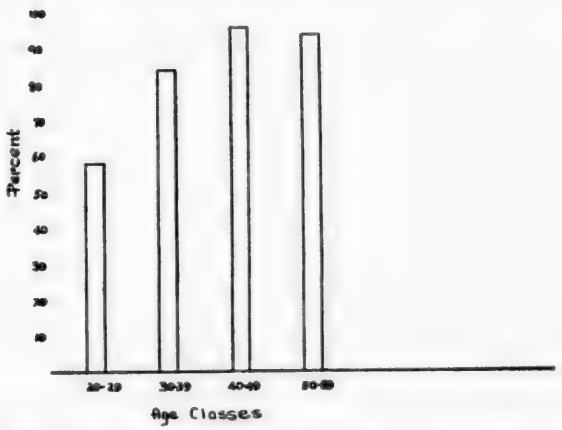

FIG. 11. The prevalence of exposure of 1.0 m.m., or more, in individuals of the various age classes.

remaining in this man's mouth, none showed any exposure whatever. For this reason it is felt that the lessened percentage in the 50–59 age group is not significant. A visual presentation of the data is given in *fig. 11.*

On a basis on 1.0 m.m. of cervical exposure on a tooth being the minimum which is significant from the point of abrasion, the individuals of all the age classes of the group studied were extremely involved. This involvement ranged from 58 per cent in the 20–29 year group to 96 per cent in the 40–49 year group.

It should be born in mind, however, that in the areas of the greatest

abrasion occurrence, where a sufficient number of teeth have been observed (107 teeth in the upper and lower canine, first and second premolar areas of all right-handed patients) that 6 per cent of the 22 per cent of the teeth with 1.0 m.m. exposure showed no abrasion. Lack of abrasion in the presence of extensive exposure was found in the poor hygiene group, where tooth-brushing was poorly performed. The actual conditions, such as might be determined from the examination of a much larger number of good hygiene cases than has been studied here (that is, cases where circumstances favoring abrasion were created by frequent brushing of teeth) would probably fall between the figures given above for persons in each age class showing 1.0 m.m. or more of exposure, and the figures given previously for persons of various classes showing any abrasion whatever; but the conditions would probably be nearer the former figure. This would still mean a sufficiently ex-extensive involvement of all the age classes studied to make the continual use of an even moderately abrasive dentifrice result in a marked loss of tissue from the cervical area of one or more teeth in a high percentage of individuals, especially where cross brushing technic was used.

SUMMARY AND CONCLUSION

From a study of the teeth of 200 individuals in the clinic of a dental college the following observations seem warranted: 1. The occurrence of cervical exposure of cementum (or dentin) was found to vary from 15.5 per cent of all the teeth in the 20–29 age class to 57.7 per cent of the teeth in the 50–59 age class. The exposure in the teeth of the 20–29 year group was largely confined to the 0.5 m.m. class, but increased in both numerical occurrence and greater linear dimension with increased age. The most pronounced increase was from 20–29 to the 30–39 age group. Females showed less exposure than males of the same age class. This sex difference was most pronounced in the 20–29 and 30–39 age groups. 2. Abrasion of some extent was found in the mouths of 42 per cent of the individuals of the 20–29 year group, but only 4 per cent of them showed cuts deeper than 0.5 m.m. Persons 30–39 years of age showed about the same amount of abrasion of all types as did those 20–29, but cuts in excess of 0.5 m.m. were increased to 18 per cent. In the 40–49 year group abrasion of all types

reached 76 per cent with 42 per cent showing abrasion cuts in excess of 0.5 m.m. depth. This was the peak condition seen, since the 50–59 year group showed no significant difference. 3. In selected patients showing good oral hygiene a cervical exposure of 0.5 m.m. was found to be more likely to be accompanied by no abrasion than it was to be associated with abrasion. The lowest linear measure of exposure which was generally associated with some degree of abrasion was 1.0 m.m. This might be termed the "critical exposure." 4. Comparison of exposure and the associated abrasion conditions existing in the good hygiene group, with the same conditions in a poor hygiene group indicated that true abrasion had not been confused to any appreciable degree in this study with loss of cervical tooth structure through some other agency, such as chemical erosion. In both the good and poor hygiene groups, areas receiving more brushing showed progressively increased abrasion. In a comparison between comparable tooth groupings in these good and poor hygiene classes, the good hygiene teeth exhibited about twice the percentage of abraded conditions as did the poor hygiene teeth. 5. By means of the use of the occurrence of the "critical" 1.0 m.m. exposure condition, it was determined that 58 per cent of the persons in the 20–29 year class, 84 per cent of those in the 30–39 year class, and 96 per cent of individuals beyond 40 had exposure conditions in one or more teeth capable of developing abrasion under conditions favoring such development.

THE ABRASION OF CEMENTUM AND DENTIN BY MODERN DENTIFRICES

RICHARD S. MANLY, PH.D.[1]

INTRODUCTION

The first thorough study of the relation between dentifrices and certain types of wasting of tooth tissue was reported in 1907 by W. D. Miller (1). He concluded that certain of the tooth pastes and tooth powders then in use were capable of producing wedge-shaped notches in the cervical region of anterior teeth, a conclusion based largely on the fact that he could duplicate the notches by brushing extracted teeth. Since some of the dentifrices he tested could readily grind away enamel, their ability to notch teeth was not surprising. Subsequently much attention has been given to this problem by manufacturers of dentifrices and of dentifrice abrasives, by the American Dental Association, and by investigators in dental schools, and the danger of abrasion of enamel by commercial tooth paste or powder today is presumably less than at the time of Miller's work.

Abrasion of dentin by dentifrice preparations has not excited as much general interest as the possible abrasion of enamel, but it has been the subject of several important researches. Not only Miller, but more recently Bunting and Rickert (2), Head (3), Carney (4), Wright and Fenske (5), and Kimball (6) all have demonstrated that when human dentin is rubbed with dentifrice abrasives a definite amount of the dentin is worn away. Van der Merwe (7), Ray and Chaden (8), and Smith (9) also found that other test substances with hardnesses similar to dentin were likewise subject to some wear by dentifrice abrasives. Grades of calcium carbonate and of calcium phosphate apparently incapable of damaging enamel have been found more than 10 times as abrasive toward cementum and dentin (5).

The magnitude of the wear has not been shown, however, under

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conditions closely approaching those of daily usage. Of the investigators who used dentin itself as the test substance, only Bunting (2) and Head (3) employed the tooth brush in their experiments. While Bunting produced a typical wedge-shaped notch, he did not measure the depth of abrasion. Apparently in an effort to better the reproducibility of their tests, the workers in the field have tended further and further from a qualitative duplication of the conditions prevailing during toothbrushing in the oral cavity.

The purpose of the work herein described has been to determine whether significant abrasion of cementum and dentin is produced when modern dental pastes and powders containing abrasives are tested by techniques closely approximating those customarily employed in prac-

FIG. 1. Details of the method of mounting a tooth

tical brushing of the teeth, and whether any abrasion occurs when a liquid dentifrice free from suspended solid is so tested. Completed dentifrices were tested, "since the abrasive properties may vary not only with the insoluble constituents but may be influenced by other substances . . . . " (10).

EXPERIMENTAL

Preparation of Teeth: Anterior human teeth preserved in formalin were cleaned with a brush, rinsed with water, and dried at room temperature. After several transverse notches had been filed in the apical third of each tooth to help anchor it, a Wood's metal cylinder was cast about this part of the root as shown in *fig. 1*. Then the proper side of the cylinder was flattened by melting, so that with the cylinder resting on this surface the labial-lingual profile of the tooth could be seen. The tooth was photographed in such a position, showing the profile of the enamel and a few millimeters of adjacent dentin at

the site of the brushing which was to follow. All the teeth selected for the experiments were well-preserved at this site.

Measurement of Surface Contour: The Wood's metal-cylinder bearing the tooth was clamped firmly in a special Monel metal box so that either a labial or lingual surface was uppermost. After an indentation had been made on the enamel with a small saw, the tooth was brushed lightly with a suspension of carbon black in alcohol to aid in focussing a microscope on the tooth surface. The metal box was placed in position on a special

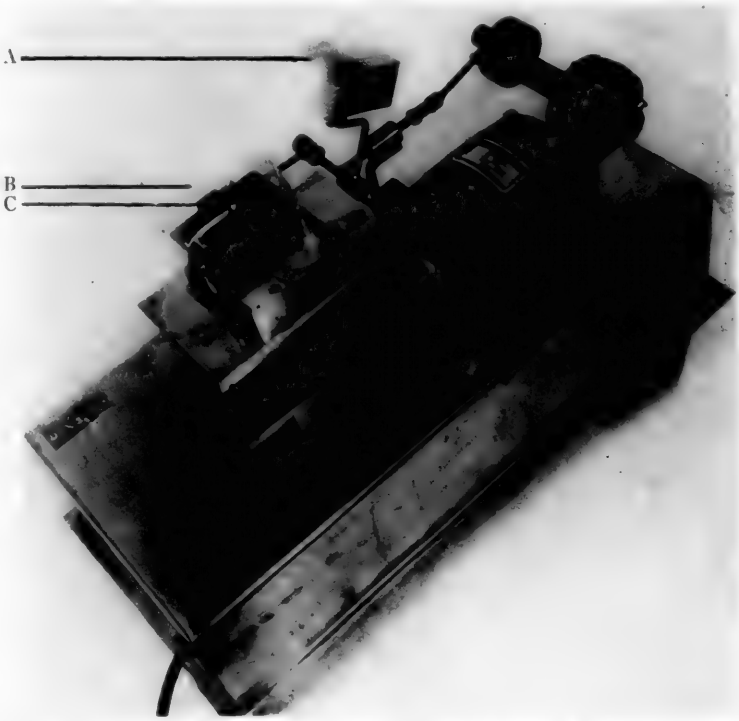

FIG. 2. Machine for brushing the teeth. A, Stirring vane; B, cellophane cover; C, load on brush.

plate fastened to a microscope stage. The plate was equipped with 2 pins fitting into tabs on either end of the box and with three spots of solder on which the box rested, in order to insure a reproducible orientation of the tooth.

For the depth measurement a Bausch and Lomb microscope was equipped with a 16 mm. objective and a 7.5X ocular fitted with cross hairs. After the microscope had been adjusted so that the intersection of the cross hairs was in focus on the bottom of the saw scratch, the fine adjustment and the stage verniers were read and recorded. The readings at this location served as a *reference point* for determining the elevation of any other loca-

tion. Without moving either the coarse adjustment or the X-axis (right to left) vernier, readings of the elevation were taken with the fine adjustment every 0.5 mm. on the Y-axis along the vertical contour of the tooth from the reference point to the Wood's metal. These readings were converted to the depth in microns below the reference point, by means of a previous calibration of the fine adjustment.

From this contour measurement qualitative evidence of abrasion can be detected with good sensitivity. The probable error of the optical measurement of elevation is 5 microns, but the greater error inherent in the stage verniers may raise this to 50 microns when the location is on a slope of 45°. The apparent "growth" of dentin, occasionally seen (liquid dentifrice tests C_1, D_1, E_2, J_1), is due to a slight sagging of the tooth in the Wood's metal, rather than to error in measurement. As a measure of differences in abrasiveness the procedure is less satisfactory. Frequently there is considerable variation in tests with the same abrasive (J_1 and J_2), probably due to variation in the shape of the teeth, which affect the division of the load between enamel and dentin, and to variation in hardness of the dentin.

Operation of the Abrasion Machine: The abrasion machine is shown in *fig. 2* with 2 metal boxes in place, one ready for operation and the other disassembled to show details of the brush mounting. The brushes used were of medium-hardness, Exton-fiber type, which had been soaked in water for 16 hours prior to use to insure uniformity of moisture conditions. The brushes were fastened to an arm reciprocating across the tooth with a 1-inch stroke at 90 cycles per minute. Fastened to the brush mountings were flat, monel-metal vanes to stir the abrasive slurry, and a small can to carry the load on the brush. This load had been adjusted to the maximum for smooth operation, giving a downward force varying from 64 to 76 grams depending on the position of the brush during the stroke.

To begin a brushing experiment, 2 parts of water were mixed with 1 part of dentifrice and enough of the mixture was added to a metal box to bring the level of the mixture just below the tooth, after the whole machine had been tilted to an angle of 18 degrees. Under these conditions the tooth remained above the dentifrice mixture but the brush dipped into the slurry and pulled it over the tooth with each stroke. After covers of water-proof cellophane or rubber had been placed over the brush and metal box to minimize evaporation, the machine was operated continuously for periods ranging from 6 to 16 hours.

At the end of the test period the slurry was washed out of the box, the tooth was dried momentarily and the surface contour measured as before from the reference point beneath the enamel surface. Any increase in the depth of the contour line served to measure the extent of abrasion.

On the reverse surface of each tooth another run was made using a liquid dentifrice. This was accomplished by inverting the tooth in the clamp and measuring the surface contour before and after an equivalent period of brushing with a 1:2 mixture of liquid dentifrice and water. Once again the tooth was photographed while resting on the flat surface of its casting, in order to disclose by photograph any major change in the profile of labial or lingual surfaces.

Dentifrices Tested: The abrasive-containing dentifrices were chosen from the leading marketed brands of paste and powder, and represent about $\frac{3}{4}$ of the abrasive-containing dentifrice sold in 1939 (11). The nature and percentage of the chief abrasive constituent for each dentifrice was obtained by analysis or from recent published literature. (Table 1). The liquid dentifrice tested is one of those which are commercially available.

TABLE I

Summary of abrasion tests at all points on cementum or dentin

TOOTH	PASTES AND POWDERS					LIQUID DENTIFRICE		
	Chief abrasive constituent	Per cent	Depth of abrasion in microns*			Depth of abrasion in microns*		
			Extreme Values		Average	Extreme Values		Average
A_1	$CaCO_3$	64	75	565	303	−55	−5	−31
A_2			25	2100	1278	−90	45	−12
B_1	Complex Na phosphate	97	420	1465	943	−5	35	11
B_2			180	370	310	−5	10	0
C_1	$CaCO_3$	89	380	510	434	−55	55	−19
C_2			460	2015	1213	−25	25	−4
D_1	Complex Na phosphate	59	355	505	452	−25	−20	−23
D_2			130	750	474	−25	15	−9
E_1	Ca phosphate	62	60	555	307	−15	−10	−14
E_2			−25	760	506	−65	−30	−47
F_1	$CaCO_3$	34	−30	565	405	−10	30	2
F_2			520	895	696	−30	−10	−19
G_1	$CaCO_3$	66	325	500	382	−70	−5	−15
G_2			20	455	286	10	45	23
H_1	$CaCO_3$	37	25	330	171	−15	70	11
H_2			125	270	199	−10	0	−6
I_1	$CaCO_3$	42	210	475	320	−5	20	9
I_2			195	440	331	−25	−10	−17
J_1	$CaCO_3$	48	85	935	597	−60	15	−34
J_2			115	380	290	0	25	17
Algebraic average					498			−8.8

* Negative values suggest an apparent "growth" and positive values indicate an apparent "wear" of the cementum or dentin. Obviously all negative values are due to experimental error.

RESULTS

In *figs. 3, 4, 5* and *6*, the abrasiveness of 10 abrasive-containing dentifrices are compared in duplicate with that of 1 liquid dentifrice.

Each abrasive-containing brand of dentifrice is designated by letter, and duplicates are distinguished by subscripts. The A, B, and C experiments were made on 3 tooth powders, and the remainder on tooth pastes. Experiments A_1, B_2 and C_1 had durations of 11.7, 5.8 and 5.5 hours respectively for both the abrasive-containing and liquid dentifrices; the remainder were 16 hour experiments.

To facilitate a comparison of the tooth profiles before and after brushing, the pictures taken after brushing were split and the halves have been placed on either side of the corresponding "before" pictures. Along the outer edges of the figures are plotted the contour measurements taken before (solid line) and after (dotted line) the brushings. The scales for the contours are shown by the lengths of the diverging arrows. Because of its greater precision, the depth measurement has usually been exaggerated 5 times in comparison with the distance measured along the tooth.

From *figs. 3, 4, 5* and *6* it can be seen that 16 hours brushing with some of the modern, abrasive-containing dentifrices will produce a notch in the cementum and dentin, even though there is no evidence that enamel undergoes abrasion. The form of the notch approaches the wedge-shaped defects that Miller described, when there is only a narrow exposure of cementum (Experiments A_1, B_1, D_1, E_1, E_2, and J_2). That a definite amount of the softer calcified tissues is lost in every one of the experiments is apparent in the contour measurements, and it is usually visible in the profile change.

On the contrary no measurable wear is obtained when the reverse sides of the 20 teeth are brushed with liquid dentifrice which contains no abrasive. This can be seen from Table I, a compilation from all the measurements on cementum and dentin. For each location on cementum or dentin there was calculated the difference in elevation as measured before and after brushing. The differences for each experiment were averaged algebraically and the average recorded in Table I along with the extreme values. The 20 experiments on liquid dentifrice have extreme values for the differences ranging from -90 to $+70$ microns, showing that the elevations of all cementum locations checked within 0.1 mm. as measured before and after brushing. The algebraic averages for the 20 experiments with liquid dentifrice have a range from -47 to $+23$, and have a mean of -8.8, which would sug-

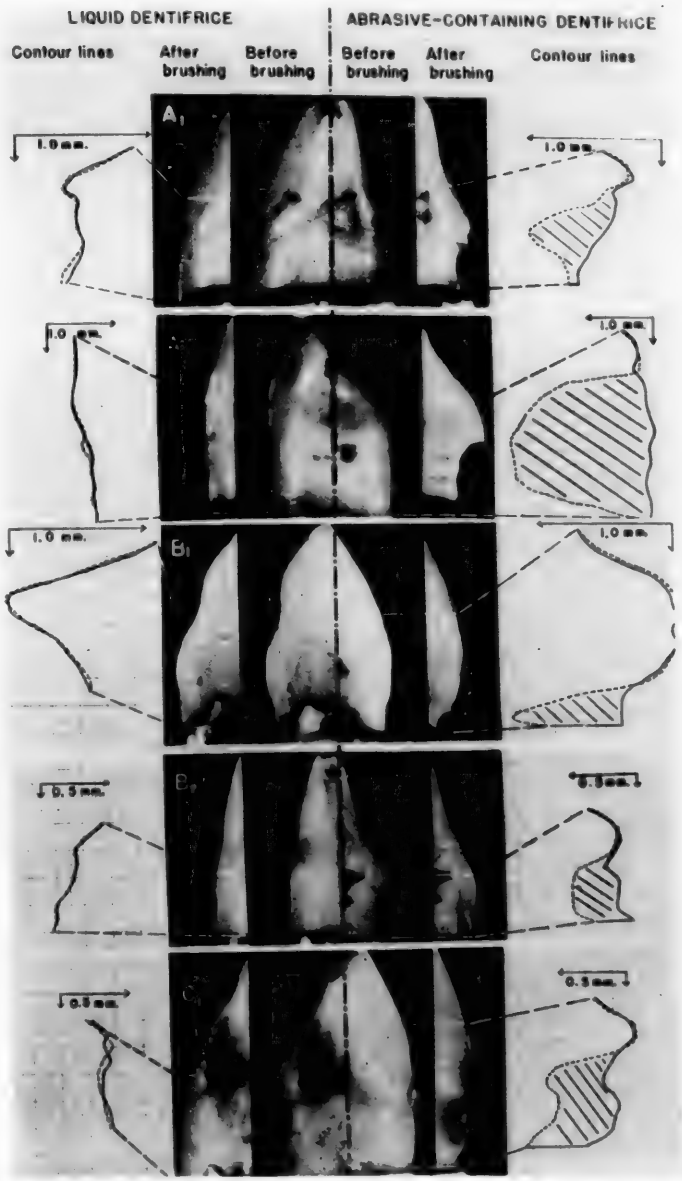

FIG. 3. A graphic and photographic comparison of liquid and abrasive-containing dentifrices as to cementum and dentin abrasion.

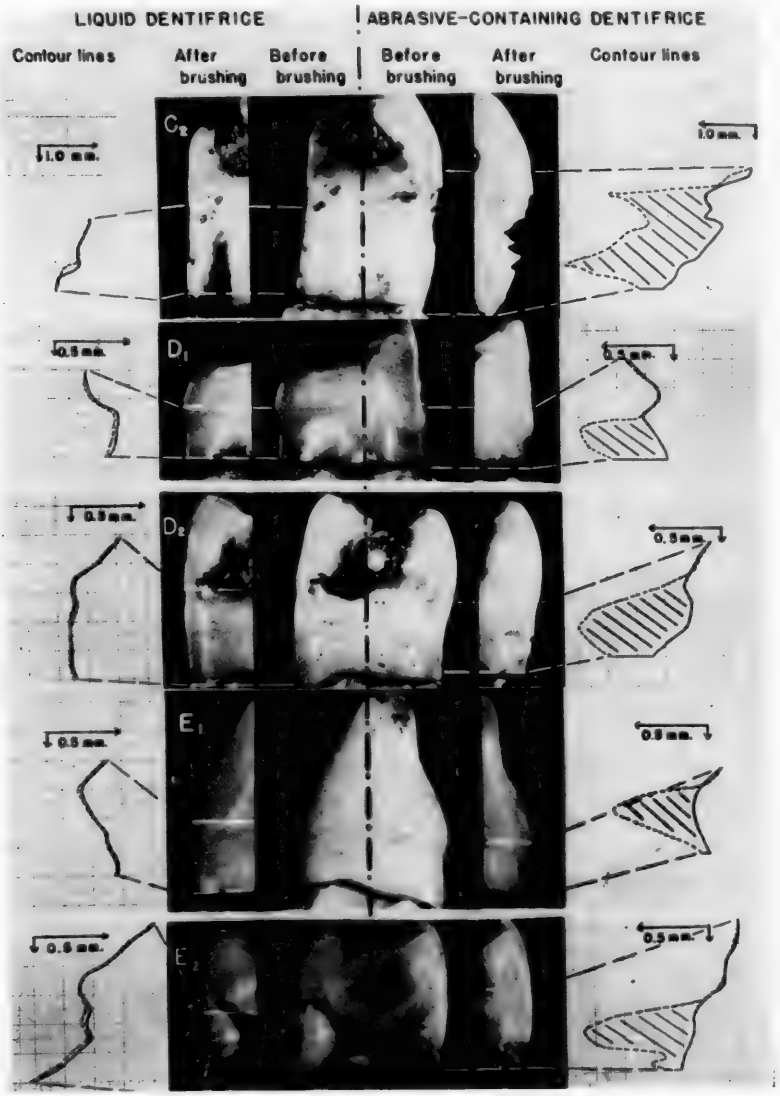

FIG. 4. A graphic and photographic comparison of liquid and abrasive-containing dentifrices as to cementum and dentin abrasion.

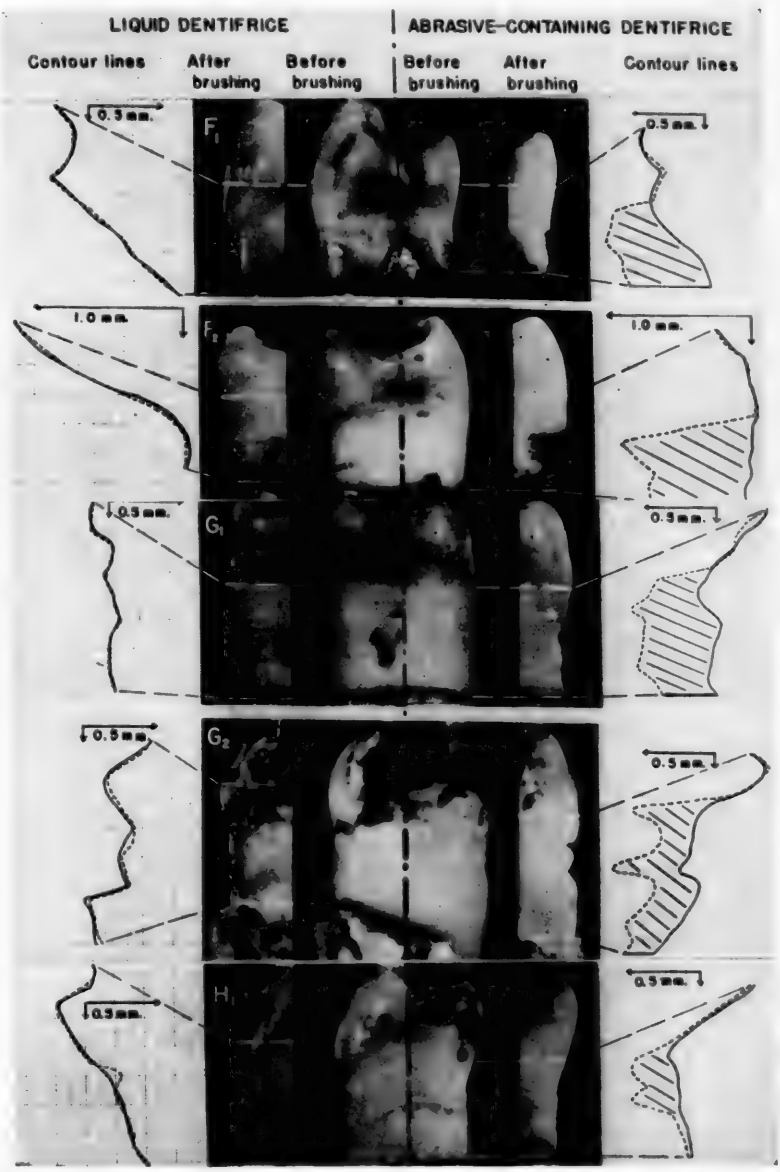

FIG. 5. A graphic and photographic comparison of liquid and abrasive-containing dentifrices as to cementum and dentin abrasion.

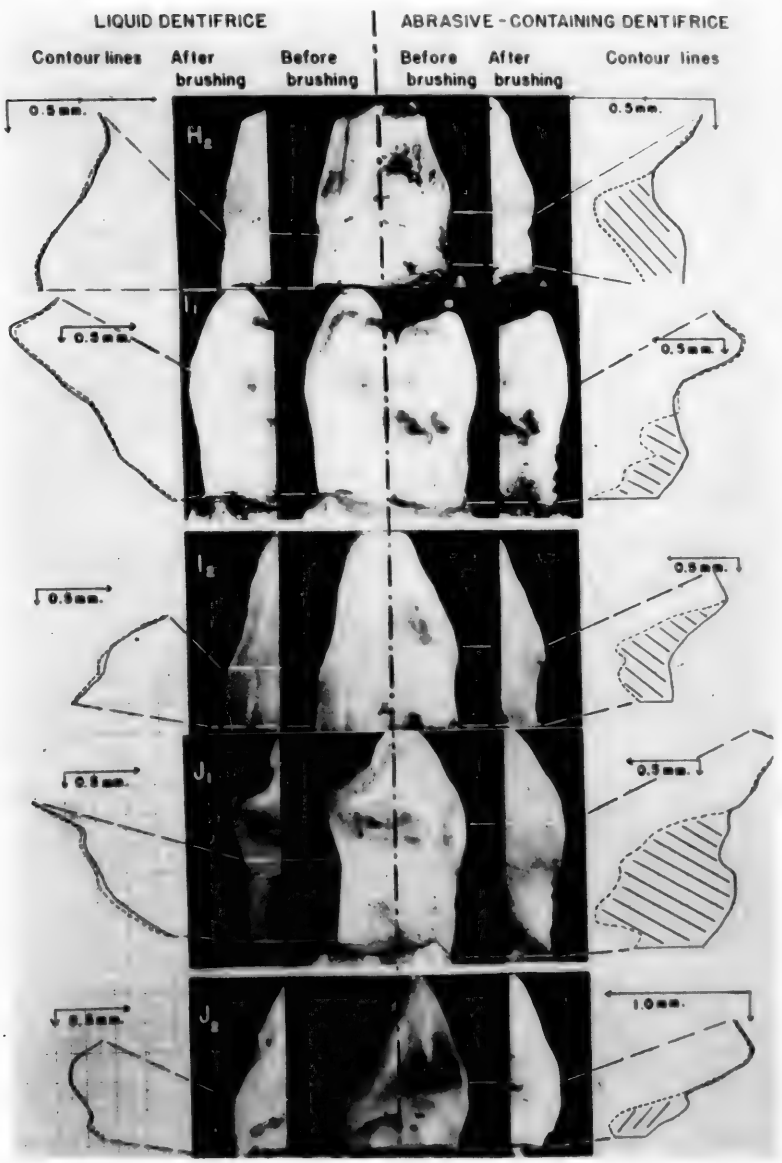

FIG. 6. A graphic and photographic comparison of liquid and abrasive-containing dentifrices as to cementum and dentin abrasion.

gest a slight "growth" of cementum rather than wear. Hence there has been no measurable wear of the softer calcified structures due to brushing with liquid dentifrice.

The average abrasion by all the pastes and powders tested ranged from 171 to 1278 microns for the individual experiments. There is no overlapping between these values and the averages for the liquid dentifrice experiments (−47 to +23). The mean wear experienced on cementum or dentin in all the paste and powder experiments is 498 microns or about 0.5 millimeters.

DISCUSSION

The finding that dentin can be abraded by certain modern dentifrice abrasives is in agreement with other workers who have used dentin as a test material (2, 3, 4, 5, 6).

The use of antimony or other metals as a means of judging the abrasiveness of pastes or powders toward dentin is not to be recommended. Wright and Fenske (5) concluded that antimony did not give a true measure of dentin abrasion from their comparison of the weight losses of antimony with the distances of wear into dentin, when 10 abrasives were tested on both materials. Furthermore antimony is apparently more resistant to abrasion than dentin, which may account for the low abrasion losses on antimony reported by Ray and Chaden (8), Wright and Fenske (5) and Smith (9) for selected dentifrice abrasives. The greater abrasion resistance of antimony is apparent when Wright and Fenske's data on the weight loss of antimony is converted into the distance of wear into that substance. For one abrasive in their table, the weight loss of 1.4 mg. of antimony amounts to only 0.40 microns of wear per kilometer of contact with the abrasive, calculated from the area exposed to wear and the density of antimony. With the same abrasive 60 microns of wear per kilometer of contact were experienced by dentin, nearly 150 times as much. Only with the 3 coarser abrasives out of the 10 tested does the depth of wear with antimony and dentin approach equality, yet it was just these 3 abrasives that Smith (12) disregarded in his criticism of Wright and Fenske's interpretations. Until further data are available it would seem logical to conclude that antimony is so much more resistant to abrasion that it should not be used to estimate dentin wear.

In addition to the use of dentin, other precautions were taken in this investigation to reproduce *in vivo* brushing as closely as possible. Medium-hardness brushes and transverse brushing were employed to duplicate customary habits. The load on the brush was adjusted to somewhat less than the manual pressure ordinarily applied. A 33 per cent concentration of dentifrice was chosen as being comparable to conditions in the mouth, where the dentifrice is applied first in a barely moistened state and later becomes diluted with several volumes of saliva.

There remains the question of the number of years of daily brushing to which these experiments are equivalent. To approximate this, the time spent by 11 persons in brushing the upper left canine region of the mouth was determined by stop watch. These persons were instructed to make their usual brushing but were not informed as to what was being timed. From their rates of brushing, the number of daily brushings and the time used, it was calculated that an average of 40 strokes per day are made on this part of the mouth. On this basis the 86,400 strokes used in our tests would be equivalent to 6 years of average brushing, and the abrasion demonstrated in vitro should be produced in vivo within 6 years. Most of the teeth in the mouth are subject to brushing for much longer than 6 years. Therefore we believe that significant abrasion, such as the wedge-shaped areas noted by Ferrier (13) in 20 per cent of the teeth requiring filling, may be expected whenever there is cementum exposure in the mouth of a person who uses average hygiene with abrasive-containing dentifrices.

SUMMARY

Ten abrasive-containing dentifrices, representing about $\frac{3}{4}$ of the sales of such products, were tested in duplicate for their abrasion of cementum and dentine by a procedure designed to reproduce oral conditions. As shown by photograph and by measurement of the tooth contour, all the dentifrices produced wear of the softer calcified structures ranging from 0.2 to 2.1 millimeters after 86,400 brush strokes, probably equivalent to six years of average daily brushing. In contrast to this a commercial liquid dentifrice failed to produce measurable abrasion when tested in an identical manner on the reverse surfaces of the same teeth.

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PAST AND PRESENT METHODS AND RESULTS OF SUGAR ANALYSIS OF SALIVA[1]

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The belief that sugar exerts a harmful effect on teeth has been taught by the dental profession and accepted by the public for many years, even though biochemically very little is known about the various types of sugars in solution in the oral secretion. The inadequacy of the information available on this question of inestimable importance prompted an investigation to determine: first, whether glucose[2] is a normal constituent of human saliva and, if so, in what quantities it is present; second, whether glucose is present in the saliva—possibly in increased or decreased amounts—under pathological conditions such as diabetes, glycosuria and uremic nephritis; and third, whether the ingestion of sugars would temporarily raise the salivary sugar content.[3]

Since a large number of experiments have been conducted on animals, a historic survey is given below.

LITERATURE

A.—*Sugar Analysis of Saliva of Animals*

In 1891, Wegert (48) found that glucose does not appear in the saliva of the dog until the blood sugar has been increased to 800 mg. per cent or more. These results were confirmed by Asher (48) in 1908. In this same year, Jappelli (58) observed that glucose is not present in the submaxillary saliva of the dog, with normal blood sugar levels, nor in the animal in which the blood sugar has been raised by

[1] Conducted under a Carnegie Fellowship grant. (Received for publication March 26, 1941.)

[2] Most investigators agree that the substance ordinarily found in blood and determined by accepted sugar analyses represents glucose. Henceforth, the word sugar will denote glucose.

[3] This paper deals only with the first part of question one: whether glucose is a normal constituent of human saliva.

the injection of glucose. He did find, however, that if sucrose or lactose were injected intravenously, these sugars would appear in the saliva, though only in minimal amounts.

In 1908, Carlson and Ryan (25), working with cats, reported the presence of glucose in the saliva collected during anesthesia. They also found traces in "normal reflex" saliva. Cannulas were inserted in the ducts of Stenson under local anesthesia, and pure parotid saliva secured by stimulation of the mucous membrane of the mouth with ether vapor or weak acetic acid or by hypodermic injections of pilocarpin. All of their samples were deproteinized by the use of acetic acid. They used the fermentation test, Fehling's test, safranin test and the phenylhydrazine test in their experiment. Carlson and Ryan also tried to determine the relation of the sugar in the blood to the concentration of sugar in reflex saliva. The glucose concentration of the blood was varied through the injection of glucose. They found that hyperglycemia was invariably followed by a great increase in the glucose concentration of "normal reflex" and stimulated saliva. They also found that there was a gradual increase of glucose in the successive samples of saliva secreted during anesthesia, that the parotid saliva contained a smaller percentage of glucose than did the submaxillary saliva, and that submaxillary saliva produced by stimulation of the cervical sympathetic nerve contains more glucose than that obtained by stimulation of the chorda tympani.

In 1909, Mestrezat and Lisbonne (70) repeated the experiments performed by Carlson and Ryan and concluded that in the normal physiological state the saliva of a cat probably does not contain sugar. Fehling's test was negative for the submaxillary saliva of 3 cats anesthetized with chloral; in a cat rendered hyperglycemic through the administration of 7 grams of a 10 per cent glucose solution, Fehling's test was positive. Under these conditions glucose was detected in the saliva; however, not until 2 hours after injection. Using Fehling's test, no sugar was found in the saliva of 2 cats at the beginning of ether anesthesia, but in one under anesthesia for 1½ hours, the saliva obtained by stimulation of the chorda tympani contained 123 mg. per cent of glucose. This difference between results obtained using the 2 anesthetics was believed to be due to the fact that ether produced a hyperglycemia while chloral did not affect the glycemia.

In 1916, Pearce (78) observed that the salivary juice of dogs rendered glycosuric by phlorhizin sometimes contained a reducing substance. His experimental procedure was as follows: The submaxillary gland was made to secrete by stimulation of the chorda tympani and the saliva collected by means of a cannula inserted into Wharton's Duct. The reducing power of the saliva of normal dogs and of animals poisoned with phlorhizin was tested by means of Nylander's test and Benedict's test and the picric acid reduction test. Sugar was not present in the saliva of normal dogs except in the case of one animal wherein the concentration of the blood glucose was 180 mg. per cent and that of salivary glucose 40 mg. per cent. In the saliva of 4 of 9 dogs to which phlorhizin had been administered the results were positive.

In 1924, Hirayama (53) working mainly with male rabbits, found reducing substances present in the saliva of normal animals and animals injected with phlorhizin in about equal amounts. Cannulas were inserted into the parotid and submaxillary glands and the secretions stimulated by intravenous injection of 1 to 3 c.c. of a 0.1 per cent pilocarpin solution. The rate of flow was noted. Each sample was deproteinized by colloidal iron hydroxide and the water clear filtrate concentrated on a water bath. The sugar content of the sample was determined by the method of Greiner (43), a modification of Bertrand's method (20).

In 1920, Achard and Ribot (85) observed the elimination of sugar in the saliva of a depancreatized dog (having 0.3 per cent glucose in the blood) after injection of pilocarpin.

In 1922, Anrep and Cannon (4) demonstrated that during the secretion of saliva the submaxillary gland consumed an increased amount of sugar from the blood. This sugar was not passed into the saliva, since the fluid did not contain sugar in determinable amounts. In some cases secretion was promoted by pilocarpin or by stimulating the chorda; in others, the samples were taken from a dog with a salivary fistula. Fehling's test and Cramer's test were carried out after the precipitation of mucin by alcohol. All results were negative, even when 20 c.c. samples of saliva were used.

In 1932, Amberson and Höber (2) investigated the permeability of the salivary glands of the cat for various organic non-electrolytes and

found that glucose penetrated the glands only in small amounts or not at all. The small size of the gland makes it impossible to secure more than 0.7 to 1 c.c. of saliva. After a ten fold dilution with water, the protein was removed from the specimen either by phosphotungstic acid, or meta phosphoric acid, or trichloracetic acid. The analysis was carried out by means of the Hagedorn-Jensen method.

In 1936, Hebb and Stavraky (48) experimented with postabsorptive nembutalized cats to determine the presence of glucose in the salivary secretions of the normal animal and in the animal after the administration of adrenalin. These workers did not find glucose in the submaxillary saliva of the cat under ordinary conditions, but found it after injections of adrenalin. They concluded that the presence of glucose in the saliva after the administration of adrenalin was due to the action of adrenalin on the salivary gland itself and not to the hyperglycemia produced by the adrenalin. They also found that in anesthetized cats the saliva secreted by the submaxillary gland through a cannula in response to stimulation of the chorda tympani or the cervical sympathetic nerve is free from glucose unless the blood sugar concentration is higher than 400 mg. per cent. The chorda tympani and the cervical sympathetic nerves were isolated and cut and rhythmic stimulation with a Palmer coil applied at regular intervals. The blood sugar concentration was determined by the Hagedorn-Jensen method. The salivary results were obtained by a comparison of the reducing substance in the protein-free filtrate before and after yeast fermentation. Deproteinization was accomplished with zinc hydroxide and the reducing substances determined according to the Hagedorn-Jensen method. The fermentation of the protein-free filtrate with yeast was carried out according to the method of Peters and Van Slyke (1932).

In summarizing the results, it can be stated that in only 3 investigations [Carlson and Ryan (cats), Hirayama (rabbits) and Amberson and Höber (cats)] sugar was found to be a normal constituent of the secretions of the salivary glands, while in 7 others, 5 of which were on dogs (Wegert, Asher, Jappelli, Pearce, and Anrep and Cannon) and 2 on cats (Mestrezat and Lisbonne and Hebb and Stavraky) the presence of sugar in the saliva was definitely denied. It is interesting to note that even though Hebb and Stavraky and Pearce could not

find sugar in normal animals, they observed that glucose was present after the administration of adrenalin and phlorhizin respectively. Hirayama found that phlorhizin does not increase the saliva sugars. Mestrezat and Lisbonne, Wegert, Asher, and Pearce observed that when the normal blood sugar level was raised, glucose was detected in the saliva. Carlson and Ryan found that glucose injections were invariably followed by a great increase in the saliva sugar. Jappelli was not able to find any glucose in the saliva after glucose injections, but did find upon the injection of sucrose or lactose that these sugars appeared in the saliva in minimal amounts. Archard and Ribot observed the elimination of sugar in the saliva of a depancreatized dog after injection of pilocarpin.

B.—*Sugar Analysis of Mixed Human Saliva*

A survey of the literature covering the analysis of the salivary sugar content of human beings reveals that of the small number of reports to be found, only a few furnish quantitative data. Twenty-two reports dealing with the examination of human mixed saliva for sugar content were available; however, the majority of which were concerned mainly with patients with various pathological conditions, in particular, diabetes. In a large number of reports, detailed information as to the health of the persons is lacking. This omission renders the data questionable for comparative purposes.

The results on the concentration of glucose in the saliva show very wide ranges for healthy individuals and for diabetics. Before discussing detailed information, it is expedient to consider some of the factors that may have led to this wide variation.

1. *Selection of material.* There are many factors which may influence the composition of mixed saliva. Only a few of these factors have been considered and reported by the various investigators. Some of these factors are:

(a) The age of the patient. It has been demonstrated that the calcium and phosphorus content of the saliva (12, 12a) may differ greatly during various periods of life. This possibility must also be considered for the glucose content of saliva.

(b) Selection of resting or activated saliva. The chemical composition of saliva is much less subject to irregularities when collected from the quiescent or resting glands than when obtained by stimulation (73, 13, 14, 15, 22, 23). Activated saliva differs markedly from resting saliva in volume and chemical content.

(c) Preliminary cleansing of the teeth. Prophylaxis is essential in order to eliminate the chance of food residue providing a source of glucose.
(d) Before or after eating. If the saliva sample is taken following a meal, possibly with a high carbohydrate content, without previous adequate cleansing of the mouth, and in addition to this the saliva is activated by chewing paraffin, it must be expected that the results will vary greatly from case to case.
(e) Vigorousness of activation. This is also known to influence the chemical composition (73, 23a).
(f) Rates of flow of both activated and resting saliva. This varies among different individuals and in the same individual at different times (11, 16, 101); therefore, records must be kept of the time of collection and the volume of the sample.
(g) Dietary habits. These may also prove of importance because of a possible excretory function.
(h) Race, sex (5, 6, 40, 44) and habitat of patient. These must be recorded.
(i) Season of the year. This has been stated to influence the oral pathology (31).
(j) Dental and physical health. These must be known for a proper evaluation of results (21, 26, 40, 42, 50, 56, 57, 69, 76, 96, 103, 104, 105).
(k) Occupational work and exercise. Physical exercise immediately before collection of a sample must be recorded (30, 79).
(l) Smoking habits. These have been said to influence the blood sugar level (7, 29, 46).

In addition to these factors that may influence the composition of mixed resting saliva, there must be added some chemical factors that may influence the analytical results. Some of the chemical factors are:

(a) Length of time the sample is kept after collection. Hiller, Lindner and Van Slyke (52) state that regardless of the amount of glucose present, incubation will destroy it. Prinz and Greenbaum (84) state that it is important to analyze a salivary sample as soon as it is collected since reducing bodies may be derived from the decomposition of mucin. Kirk (61) quoted Michaels as stating "that the saliva contains large quantities of bacteria, and unless certain precautions are taken the contained sugar disappears by fermentation."
(b) Ferments. The carbohydrate-splitting enzymes of human saliva may increase or decrease the sugar content (27, 38, 47, 82, 83, 84, 102).
(c) pH of the saliva. This may have an effect upon the analytical results.

2. *Chemical procedures of salivary sugar analysis.* There are 2 distinct processes involved in the analysis of salivary sugars: the removal of reducing non-carbohydrate substances by deproteinization and the determination of sugar.

a—*Removal of Reducing Non-Carbohydrate Substances.* Since no chemical method is specific for glucose, the removal of non-glucose reducing substances by deproteinization is necessary, otherwise they will influence the analytical results. It is apparent from the litera-

ture (52, 54, 55, 75, 91, 92, 93) that there is a demonstrable, though small, amount of reducing substance present in biological fluids which cannot be attributed to glucose. The nature, concentration and physiological behavior of these reducing substances, which are only partially known, may be of considerable importance. Their concentration may vary considerably under different physiological and pathological (21, 56, 68) conditions, and it is by no means certain that the same group of substances is always involved. It is known that uric acid, creatine, creatinine, glucuronic acid, pentoses, disaccharides, purines, and adrenalin (52) have the power of reducing the reagents commonly used in glucose determinations.

Many reagents have been employed for the deproteinization of saliva. Some of these are: alcohol, acetic acid, saturated picric acid, trichloracetic acid and kaolin, tungstic acid, tungstic acid with calcium chloride and kaolin, acetic acid with ammonium sulfate or lead acetate, alumina cream, Almen's solution, and 10 per cent sodium tungstate and 2/3 N sulfuric acid. However, most of these are not widely used now because it has been shown (17, 18, 41, 51, 86, 90, 91, 92, 93) that they are not as satisfactory as the present day methods for the removal of interferring substances. Also some of these methods are no longer used because they were uncommonly cumbersome (67, 98).

Modern deproteinization technics have been tested for their efficacy in removing reducing non-carbohydrates by measuring the reducing substances present before and after yeast fermentation. Somogyi (93) determined the amount of reducing non-sugars in blood filtrates prepared by 3 methods of deproteinization: Folin-Wu (36, 37), Hagedorn-Jensen (45), and Somogyi's zinc method (93). The Shaffer-Hartman Procedure (87) was used for determining the sugar present. Somogyi found that after the sugar was removed by yeast the zinc filtrates contain "virtually none of the reducing substances in the blood," and that the Hagedorn-Jensen filtrates contained in 10 tests between 5 and 12 mg. per cent, and the Folin-Wu filtrates 14 to 26 mg. per cent. From these results, Somogyi reasoned that if the zinc filtrates contain sugar as the "sole substance oxidizable by alkaline copper reagents," then different methods for the determination of sugar should yield identical results. He therefore used them with 4 different sugar methods: Folin-Wu, Benedict's (17, 18), Folin's

(34) modification of the Folin-Wu, and Shaffer-Hartman. The results of this experiment showed that the 4 procedures give substantially identical sugar values. Besides this zinc precipitation procedure, Somogyi has developed a copper precipitation procedure which is superior to the zinc for the precipitation of plasma or serum proteins (94). Today the zinc and copper deproteinizing reagents of Somogyi are recommended because they eliminate more interference from non-carbohydrate reducing bodies than do other reagents.

b—*Qualitative Methods of Salivary Sugar Analysis.* In the past, many investigators have used qualitative tests to detect the presence of glucose in saliva. The various methods used were: Fehling (32, 61, 62, 74, 80), Fehling-Benedict (81), fermentation (61, 88, 89, 106), phenylhydrazine (10, 27, 28, 33, 76, 80, 84, 106), Nessler's method (71, 72), Nylander (106), Molisch (80), Williams' diabetic test (32), and Barfoed (80). In order to detect the minute traces of glucose that may exist in saliva (Table V), these methods require the use of large quantities of saliva approximately 20 c.c. or more (often impossible to obtain unless several samples are pooled). Because glucose is one constituent that requires more concentration for qualitative than quantitative methods and since only 3 investigators (Tables I and III) have reported the amount of sample used, the results of these qualitative tests can only be viewed with historical interest.

c—*Quantitative Methods of Salivary Sugar Analysis.* With the use of modern quantitative methods, one is able to estimate a smaller amount of sugar than could be detected qualitatively by older methods. Today one has the more reliable and accurate methods of Hagedorn-Jensen, Folin-Wu, Benedict, and Folin (35). These have surpassed the earlier procedures devised by Kahn (60), Bang (8, 9), Bang, Condorelli (67), and Bertrand's modifications.

The methods which are in general use in modern biological research are all based on the power of glucose to reduce various substances in alkaline solution. Only 2 of these have been applied to salivary sugar determinations: first, the reduction of alkaline copper solutions by the sugar and determination of the reduced copper in various ways as by the methods of Benedict, Shaffer-Hartman, Somogyi, and Folin-Wu, and, second, the reduction of alkaline ferricyanide solutions and the determination of the excess ferricyanide by either the methods of

Hagedorn-Jensen, Van Slyke and Hawkins (99) or Folin. All these methods require the use of an empirically determined factor to convert the volumetric or colorimetric data into figures representing the corresponding amount of glucose, i.e., no stoichiometrical, or even constant, ratio may be used.

Several micro-methods have been adapted with success to small samples of blood (0.1 c.c.), but the concentration of glucose in these small samples of blood is much greater than that found in a corresponding amount of normal resting saliva (Table V). So if the same amount of saliva (0.1 c.c.) is used, results of sufficient accuracy cannot be expected. Small samples with very dilute concentrations cannot be adapted to ordinary micro-equipment.

3. *Former procedures and results of salivary sugar analysis in healthy individuals.* During the process of evaluating results of former investigators who have analyzed the saliva of normal healthy individuals, it became evident that 6 workers (Pickerill (81), Perlzweig, Weisman (80), E. C. Kirk, Simon, and Dessy) used qualitative methods (Table I, Group I). The results by these methods, as mentioned, cannot be evaluated. In addition, these authors did not present certain important data with regard to selection of material and chemical procedure. These omissions are marked by a question mark in Table I.

The results obtained by quantitative methods (Table I, Group II) should supply more accurate information; therefore, a critical analysis of the selection of material and chemical procedures was made.

In 1914, Perlzweig found sugar present by using Benedict's colorimetric method. Two individuals were examined in which the average yield of glucose was 17.6 mg. per cent. Weisman, who worked in the same laboratory as Perlzweig, used Kahn's Method with deproteinized saliva. He found the presence of 2.8 mg. of glucose in 25 c.c. of saliva. Neither Perlzweig nor Weisman described the conditions at the time of collection but they did perform their analyses immediately upon collection of the sample. They used an accepted method for glucose determination, but their deproteinization procedure may have permitted the retention of non-glucose reducing substances, thereby raising the glucose results. Because they omitted some essential data and used activated saliva, their results cannot be accepted for comparative purposes.

TABLE I

*Material, chemical technics and results of former salivary sugar analyses in healthy individuals**

GROUP	AUTHOR	YEAR	NO. OF CASES	BEFORE OR AFTER EATING	RS† AS‡	RATE OF FLOW PER HOUR C.C./HR.	SEX	AGE	DENTAL HEALTH	PREPARATION OF PATIENT	SALIVA FOR SINGLE DETERMINATION, C.C.	DEPROTEINIZATION	QUALITATIVE METHODS	GLUCOSE RESULTS
I	Pickerill	1912	?	?	?	?	?	?	?	?	?	?	?	Negative
	Perlzweig**	1914	2	?	AS	?	Sex noted	Age young	Susceptible to caries	?	a—1 b—2-3	a—2% acetic acid b—Saturated picric acid c—Deproteinized immediately	a—Fehling b—Fehling-Benedict c—Barfoed	Negative Negative
	Weisman	1914	?	?	AS	?	Sex noted	Age young	Susceptible to caries	?	30	a—Dialysis of 25 c.c. portions of fresh normal saliva in collodion bags over night b—Removal of proteins by treatment with acetic acid and ammonium sulfate, with lead acetate or with cream of alumina	a—Molisch b—Fehling-Benedict c—Phenylhydrazine	Negative Negative
	Kirk, E. C.**	1914	?	?	?	?	?	?	Susceptible to caries	?	?	?	a—Fehling b—Fermentation	Positive
	Simon**	1926	?	?	?	?	Sex noted	Age noted	Noted	?	?	?	Fermentation	Positive
	Dessy	1935	?	?	?	?	?	?	?	?	?	10% Na_2WO_4 and 2/3 N H_2SO_4	Phenylhydrazine	Negative

													QUANTITATIVE METHODS	MG. %—RANGE	MG. %—AVERAGE
	Perlzweig**	1914	2	?	AS	?	Sex noted Age young	Susceptible to caries	?	10	Same as Perlzweig in Group I		Benedict's Colorimetric Method	13.5–21.0	17.6
	Weisman	1914	1	?	AS	?	Sex noted Age young	Susceptible to caries	?	?	Same as Weisman in Group I		Kahn's Method		11.2
	Prinz	1918	?	After	AS	?	Both noted	Noted	?	?	?		a—Bang b—Bertrand as modified by Michaels & Rona	Negative	
	Morris** Jersey	1923	?	?	RS AS	Noted	Both noted	?	?	?	2% acetic acid 10 sodium sulfate Alumina cream		Folin-Wu	Negative	
II	Updegraff Lewis	1924	68 3 people given 100 to 300 gm. glucose	1 to 1½ hours after light breakfast	AS	Noted	Probably noted	?	Mouth washed with water	?	a—Trichloracetic acid and kaolin b—Tungstic acid in presence of small amount of $CaCl_2$ c—See page 10 (98) d—Deproteinized immediately		Folin-Wu	Not enough reducing substance for quantitative estimation	
	Simon**	1926	73♀ 123♂	?	?	?	14—over 50♀ 14—over 50♂	Noted	?	0.5			Hagedorn-Jensen	1–107♀ 3–149♂	24♀ 26♂
	Luisada	1934	31	?	AS	?	? ?	?	Mouth washed with water	0.5	Deproteinized saliva Undeproteinized saliva		Bang-Condorelli	3–15 10–30	
	Dessy	1935	17	?	?	?	? ?	?	?	0.4	10% Na_2WO_4 and 2/3 N H_2SO_4		a—Folin-Wu as modified by Fontes & Thivalle b—Bang-Condorelli c—Hagedorn-Jensen	Negative Positive	
	Becker Kestermann	1936	10	Before, after	RS	Noted	Sex noted Age ?	?	Mouth washed with water	0.1	3% acetic acid		Hagedorn-Jensen	Negative	

* The works of Frerichs, Verneuil and Pagliai (quoted by Luisada) were not available.
** It is assumed that the saliva of normal healthy individuals was analyzed.
† Resting saliva.
‡ Activated saliva.

In 1918, Prinz (83) found no sugar in the saliva of healthy individuals by the micro-method of Bang and also that of Bertrand as modified by Michaels and Rona. Even though he was very careful in the selection of his material, his results cannot be considered for comparative purposes because he did not use resting saliva and his samples were taken after eating.

In 1923, Morris and Jersey (73) used the Folin-Wu method. The results obtained with both resting and activated saliva, as expressed by these workers, resulted "uniformly in the absence of more color than a blank gave." These 2 authors failed to state any of the conditions at the time of collection; therefore, their results cannot be used for comparative purposes.

In 1924, Updegraff and Lewis (97, 98) examined the saliva of healthy men and women students and laboratory workers. Samples were collected from 1 to 1½ hours after a light breakfast. Each subject was required to rinse the mouth thoroughly with water. Paraffin was chewed and the first few cubic centimeters of saliva were rejected. They used the Folin-Wu reagents in their experiment and found a reduction in a few of the 68 salivas examined, but the color developed was never of sufficient intensity to permit a quantitative estimation of the amount of reducing substance present. They concluded that glucose is not normally present in human saliva in any significant amount. The results of Updegraff and Lewis cannot be used for comparative purposes because activated samples were collected after breakfast.

In 1926, Simon (88, 89) used the Hagedorn-Jensen Method and the fermentation test to analyze the saliva of 123 men and 73 women. He observed the age, sex and condition of the mouth for each patient. He found the average glucose value for men to be 26 mg. per cent and 24 mg. per cent for women. In his analytical procedure, he divided his cases according to age and sex. Simon's results ranged from 13 to 35 mg. per cent. He did not record whether the saliva was collected before or after eating, whether the teeth were cleaned before collecting the sample, the dental health, the rate of flow, whether the sample was activated or resting, and whether the patient was suffering from any metabolic disturbances. His method of deproteinization may have left residual reduction. Lack of observation of the many

factors listed above may be responsible for the wide range of results. Simon's results cannot be accepted for comparative purposes because of the incompleteness of the data.

In 1934, Luisada (67) analyzed the saliva of a number of healthy individuals selected from among medical students and physicians. Preparation of the patient included: a sugar analysis of the blood, rinsing of the mouth with water, and a rest period of 5 to 10 minutes. The patient was then requested to expectorate into a container, until 5 to 10 c.c. of saliva were collected. In those cases of limited salivary secretion, saliva was activated by mechanical stimulus such as a rubber ball or the tip of a glass rod. Bang's method was used with deproteinized and undeproteinized saliva. Higher glucose values were obtained with undeproteinized than with protein-free saliva. The glucose content in the deproteinized saliva of normal patients ranged from 3 to 15 mg. per cent, while the untreated saliva ranged from 10 to 30 mg. per cent. He further found that in healthy people there was a proportional relationship between the saliva sugar and blood sugar, that is, if the blood sugar was increased, then the salivary sugar would be increased. Luisada also studied the effect of various drugs on the sugar content of saliva. In 3 patients to whom adrenalin was given and in 1 to whom morphine was administered, an increase was noted in the blood sugar as well as in the salivary sugar. In 3 given pilocarpin, the blood sugar remained unchanged, while the salivary flow was increased and accompanied by a reduction of the salivary sugar. In 4 cases where atropin was given, neither the blood sugar nor the salivary sugar was affected. In 3 given phlorhizin, the sugar content of the saliva was augmented, but the blood sugar was not. In 2 cases, the mouth was washed with 200 grams of sugar dissolved in 250 c.c. of water. In this instance, there was an increase in the quantity of reducing substance in the saliva, which persisted for over an hour. Luisada failed to note the dental health of the patient, whether the sample was taken before or after eating, the rate of flow, and the age of the patient. Whether non-sugar reducing substances were left in appreciable amounts after deproteinization is not known. Also, he used activated saliva. For these reasons, his results cannot be used for comparative purposes; however, they are of value in showing that incomplete deproteinization will cause increased

values and that stimulation of salivary flow will reduce the glucose results. Also it is interesting to note that the local effect of a sugar intake can be detected for over an hour. This observation may be of importance since it is generally conceded that a high carbohydrate diet may play an important role in the development of dental caries and that the sugar intake affects local bacterial growth (3, 24, 59, 64, and for summaries see 1).

In 1935, Dessy (28) used the Folin-Wu method modified by Fontes and Thivalle on 12 normal individuals, with negative results. On 5 normal people he used the Bang-Condorelli, Hagedorn-Jensen, and Folin-Wu modification. Positive results were obtained with the first 2 methods, but negative results were obtained with the last. Dessy believed that the positive results with the Bang-Condorelli and Hagedorn-Jensen methods were due to inaccuracies inherent in the methods. Dessy did not record the following factors: resting or activated saliva, before or after eating, rate of flow, dental health, prophylactic measures, age, sex, and length of time the sample was stored before analysis.

In 1936, Becker and Kestermann (10) examined 10 normal individuals. Blood sugar tests were made with each salivary determination. Salivary sugar was determined in samples collected in the morning before eating and again 20 minutes after eating a meal of 400 grams of vegetable and 100 grams of fried meat. The blood sugar concentration remained about the same before and after eating. Before collecting salivary samples, the mouth was rinsed with water. Resting saliva was collected over half hour periods and measured. The Hagedorn-Jensen method was used to determine the amount of sugar in 0.7 c.c. of the filtrate which represents 0.1 c.c. of undiluted saliva. No sugar was found in the saliva of the 10 healthy persons. Even though Becker and Kestermann were very careful in the selection of material and even though they used an accepted micro-method for blood sugar, this method was not adapted for the sensitiveness required in salivary sugar analyses.

In evaluating the reported quantitative sugar investigations for healthy individuals, it may be stated that the results obtained cannot be compared because each investigator failed to account for important factors which might have influenced the results. The analytical

methods may not have been applicable to the small sample of saliva used. This factor may be of particular significance in explaining the many statements that normal resting saliva does not contain glucose.

4. *Former procedures and results of salivary sugar analyses of diabetic patients.* Most salivary analyses of diabetics have been made by qualitative methods. Only a few investigators have used quantitative procedures. Contradictory results have been reported which can only be understood when a critical study has been made of the selection of material and the chemical technics used by these workers. A summary of methods and results is given in Table II.

Thirteen investigators used *qualitative* methods (Table II, Group I) to detect the presence of glucose in the saliva of diabetics. Positive results were reported by Michaels and Ferannini; negative results by Mosler, Bernard (19, 20), Kraus (84), Noorden, Pickerill, Dessy, and Becker and Kestermann; both positive and negative cases were found by Wissel, Fleckseder, Rathery and Binet (85), and Da Rin and Weinberger.

Examination of Table II, Part II, shows that 4 investigators used *quantitative* methods (Prinz, (83) Palombella (77), Luisada, and Becker and Kestermann). Prinz could not find the faintest trace of sugar in the saliva of diabetics with a known sugar content of 7 per cent in the urine. A description of the selection of material, chemical procedure and critical discussion has been given previously.

In 1930, Palombella analyzed the saliva, blood and urine of 11 diabetics of Bang's micro-method. Salivary samples were collected at various times during the day. Sugar was found in 2 of the cases. Palombella omitted to mention how long after eating samples were taken, the contents of the meal, whether the diabetic cases were controlled or uncontrolled, whether the salivary samples were activated or resting, the rate of flow, how long after collection analyses were made, whether the teeth were cleaned before collecting the specimen and whether a dental examination was made. For these reasons, the results cannot be accepted for comparison.

In 8 diabetics, Luisada found sugar in the saliva ranging in amounts from 7 to 70 mg. per cent in deproteinized saliva and in undeproteinized saliva from 20 to 46 mg. per cent. Luisada also found that pilocarpin did not increase the saliva sugar of diabetics, while insulin

TABLE II

*Material chemical technics and results of former salivary sugar analysis of diabetic patients**

GROUP	AUTHOR	YEAR	NO. OF CASES	BEFORE OR AFTER EATING	RS AS	RATE OF FLOW PER HOUR C.C./HR.	SEX	AGE	DENTAL HEALTH	PREPARATION OF PATIENT	SALIVA FOR SINGLE DETERMINATION, C.C.	DEPROTEINIZATION	QUALITATIVE METHODS	GLUCOSE RESULTS
I	Mosler	1864	1	Before and after	AS	?	♂	29	Noted	Cleaned with water before collecting sample	?	?	Fehling	Negative
	Bernard**	1877	?	?	?	?	?		?	?	?	?	?	Negative
	Wissel	1897	9	?	AS	?	?		?	Cleaned with water before collecting sample	?	?	a—Fermentation b—Nylander c—Phenylhydrazine	1 case positive 8 cases negative
	Michaels	1904	?	?	?	?	?		?	?	?	?	Nessler's Method	Positive
	Fleckseder	1905	4	?	RS	?	?		?	Mouth cleaned	?	?	Phenylhydrazine	2 cases positive 2 cases negative
	Ferrannini	1907	1	?	?	?	?	70	?	?	?	a—Trichloracetic acid b—Reactive Almen c—Glycuronic acid removed by precipitation by neutral and basic double lead acetate	a—Fehling b—Williamson's Diabetic Test	Positive
	Kraus**		10	?	?	?	?		?	?	?	?	Phenylhydrazine	Negative
	Noorden	1912	?	?	?	?	?		?	?	?	?	Phenylhydrazine	Negative
	Pickerill	1912	?	?	?	?	?		?	?	?	?	?	Negative
	Rathery	1920	34	?	?	?	?		?	?	?	?	?	2 cases positive
	Binet**													
	Da Rin	1928	20	Before and after	RS AS	?	Sex noted Age ?		?	?	3	Centrifuged	Williamson's Diabetic Test	1 case positive
	Weinberger													
	Dessy	1935	1	?	?	?	?		?	?	?	10% Na_2WO_4 and 2/3 N H_2SO_4	Phenylhydrazine	Negative
	Becker Kestermann	1936	?	Before and after	RS	Noted	Sex noted Age ?		?	Mouth washed with water	?	3% acetic acid	Phenylhydrazine	Negative

												QUANTITATIVE METHODS	MG. %—RANGE	MG. %—AVERAGE
	Prins	1918	?	After	AS	?	Both noted	Noted	Noted	?	?	a—Bang b—Bertrand as modified by Michaels and Rona	Negative	
	Palombella	1930	11	Various times of the day	?	?	Sex noted Age 14–80	?	?	?	?	Bang's micro method	2 cases positive	
II	Luisada	1934	8	?	AS	?	?	?	Mouth washed with water	0.5	Deproteinized saliva Undeproteinized saliva	Bang-Cordorelli	7–70 mg. % 20–46 mg. %	
	Becker Kestermann	1936	23	Before and after	RS	Noted	Sex noted Age ?	?	Mouth washed with water	0.1	3% acetic acid	Hagedorn-Jensen	Before eating, 10–21 mg. %. After eating, 10–24 mg. %	

* The works of Lecorche, Pavy, Lehman, Jordeo, Nasse, Koch, Gorup-Besmann, and Arthurs (quoted by Michaels) and those of Ritter de Nancy and Miguel (quoted by Luisada) were not available.

** Unable to obtain references giving more detailed information.

caused a reduction in both blood and saliva sugar. The selection of his material and chemical technic have been discussed previously.

Becker and Kestermann studied 23 diabetic cases. These were divided into 3 groups: 7 untreated cases (Table III, Group I), 7 cases treated with insufficient amounts of insulin (Table III, Group II), and 9 controlled cases (Table III, Group III). Glucose was found in amounts of 10 to 24 mg. per cent in 13 of the 23 diabetic patients (Table III). A detailed comment on the methods of these investigators has been given in the preceding pages.

In none of the experiments observed on human saliva has a record been made of the race of the patient, region in which the patient lives

TABLE III

Sugar results in the 3 diabetic groups (according to Becker and Kestermann)

	GLUCOSE—MG. PER CENT RANGE OF RESULTS		SALIVARY FLOW CC./½ HR.	
	Before eating	20 minutes after eating	Before eating	20 minutes after eating
Group I	3 cases—neg. 4 cases—12–18	2 cases—neg. 5 cases—16–22	0–4.5	3.5– 5.5
Group II	3 cases—neg. 4 cases—15–21	2 cases—neg. 5 cases—18–24	0–4.7	2.1– 8.6
Group III	4 cases—neg. 5 cases—18–24	1 case—neg. 8 cases—10–15	2.1–7.8	3.4–10.5

or has lived (Palombella excepted), season of the year (Mosler excepted), and smoking habits. Also no experimenter seems to have checked the accuracy of his method on a test solution.

From the preceding data, it can be readily seen that the studies thus far reported have been too few in number and too limited in character for the subject to be dismissed as one clearly elucidated. If salivary sugar is to be of any value as a diagnositic tool or in correlation studies, it is imperative that a normal physiologic range and average be established.

SELECTION OF METHOD

The lack of agreement concerning the presence of glucose in normal resting and activated saliva is due not only to the selection of material and methods of deproteinization, but to the fact that investigators

failed to realize that most of the qualitative methods require at least 20 to 30 c.c. of saliva in order to detect the presence of glucose. In some cases, especially diabetics, large amounts of saliva are very difficult and often impossible to collect. With the application of accepted blood sugar micro-methods to salivary sugar, one is faced with the problem of making the method applicable to a fluid falling far less in glucose concentration than blood.

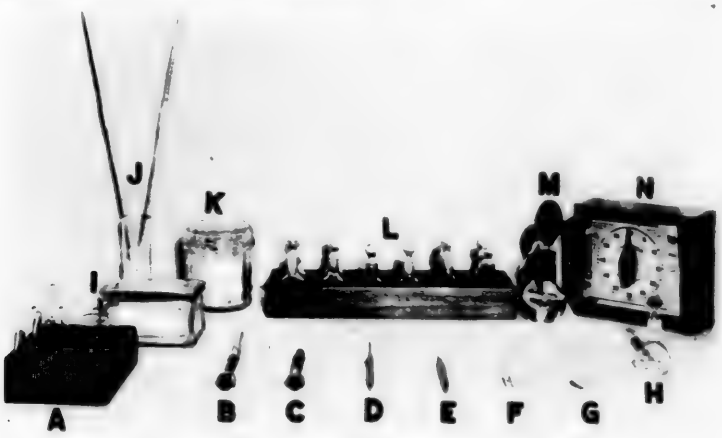

FIG. 1

Equipment required for Drop Scale Method. A—Micro test tube block, B—Syringe with capillary pipette, C—Syringe pipette control, D—Long-beak capillary pipette, E—Capillary pipette (calibrated accurately), F—Micro test tube (3 mm. inside diameter and 35 mm. length and calibrated to a convenient volume (about 200λ*)), G—White porcelain titration dish, H—Reagent flask, glass stoppered, approximately 10 c.c. capacity, I—Lens paper container, J—1 c.c. pipette, K—Cotton container, L—Block with reagent flasks, M—Wash bottle, approximately 50 c.c. capacity, N—Dee Timer.

* λ = 0.001 c.c.

A possible solution to the problem of analyzing small samples has been offered recently by Heck, Brown and Kirk (49, 39, 63, 95) who have developed an ultramicro method, the drop scale quantitative method, for the determination of reducing sugar. This method is capable of determining from 1 to 12γ[4] of sugar in a total volume of 0.2 c.c. with an accuracy of 1 to 2 per cent. The equipment necessary for this procedure of Heck, Brown and Kirk is shown in *figs. 1 and 2*.

Solutions required for this method are: 1- 7 per cent copper sulfate

[4] γ = 10^{-6} grams.

($CuSO_4 \cdot 5H_2O$), 2—10 per cent sodium tungstate ($Na_2WO_4 2H_2O$) made up with 2 per cent sodium carbonate, 3—1.5 per cent potassium ferricyanide, 4—14 per cent sodium carbonate anhydrous salt, 5—10 per cent sulfuric acid (by volume), 6—Standard ceric sulfate about 0.0025 N; standardized against pure dry potassium ferrocyanide; stored in an all glass container (66), 7—0.1 per cent Setapalin C.

The methods (39) based on the reduction of copper solutions are not favorable for use on the drop scale because of the variations in the

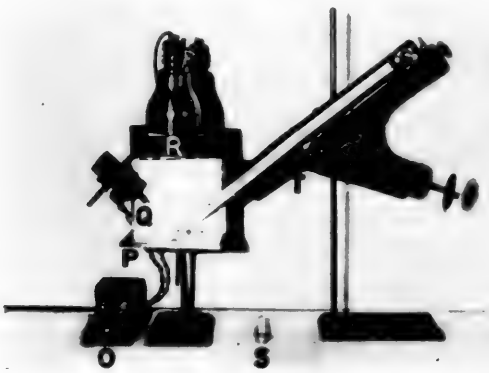

FIG. 2

Equipment required for Drop Scale Method. O—Transformer and switch for stirrer, mounted on base, P—Titration table, Q—Magnetic thread stirrer, R—Light for titration table, S—Flash light, T—Capillary burette with mercury control.

glucose equivalent. With the ferricyanide methods, the end point in the titration of the excess ferricyanide is not sufficiently sharp to permit the use of the drop scale method. However, the titration of the formed ferrocyanide with standard ceric sulfate solution does give a satisfactory end point. Experiments on the various deproteinizing reagents for drop scale work revealed that the elimination of interference by non-sugar reducing materials seems to be more successfully accomplished when modification of the Somogyi (94) copper deproteinizing reagents or Letonoff's (65) method for deproteinization is used.

The advantages of this ultra-micro method are many. For example they include not only the use of smaller samples, shorter time for the

collection of the samples and hence more prompt analysis, less laboratory space, and smaller quantities of reagents, but they also permit of investigations that might be impossible by other methods; that is, for example, when one is faced with the problem of estimating the amount of ingested sugar eliminated from the mouth every 10 minutes for an hour period (6 samples) in an individual with a low rate of flow.

EXPERIMENTAL

We have applied the ultra-micro method of Heck, Brown and Kirk and the deproteinization method of Somogyi to small quantities of saliva.

In order to interpret the results of analysis of saliva for glucose, the following data, as pointed out previously, should be obtained: a—Dental and physical health. The dental history must include the number of cavities, over-hanging fillings, artificial appliances, malocclusion, condition of the surrounding structures and care of the mouth, b—Dietary habits and diet the day before the sample is collected, c—Race, sex and habitat of the patient, d—Smoking habits, e—Season of the year, f—Rate of flow, g—Type of saliva collected (resting or activated), h—Occupation, i—Amount of exercise prior to collection of specimen, j—Careful cleaning of the mouth, k—Before or after eating, l—Length of time sample is kept, m—pH of saliva, n—Checking of the method on test solution.

Collection of Saliva. The patient is instructed to refrain from food and drink the morning the sample is taken (100). An appointment is made for 8:00 or 8:30 in the morning. If a resting sample is to be collected, the patient is requested to avoid yawning, swallowing, spitting or any other stimulation. In order to collect the sample, the patient's head is tipped forward with the mouth open, and the saliva allowed to drip through a funnel into a graduated tube. If an activated specimen is desired, the patient is instructed to chew a 1 gm. piece of paraffin 100 times on each side of the mouth and expectorate the saliva secreted into a graduated container. Time of collection and volume of sample are recorded.

Recommended Procedure. Within 10 or 15 minutes after collecting the saliva, the sample is deproteinized. The saliva filtrate is prepared in the following way: to 1 volume of saliva add 1 volume of distilled

water. One c.c. of 7 per cent copper sulfate is then added to a 1 c.c. aliquot of the 1:1 dilution of saliva. Introduce with continuous shaking 1 c.c. of the sodium tungstate-sodium carbonate reagent. Shake well and centrifuge at 2,000 R.P.M. for 10 minutes. The supernatant fluid is transferred with a pipette into another container.

The analysis of the protein-free filtrate is performed as follows: Place 50 λ of the filtrate by means of a capillary pipette into a micro test tube. Wash out the capillary pipette 3 times with small quantities of distilled water (not to exceed the total volume of the micro-test tube calibration) to be sure all the sample has been transferred to the micro test tube. To the sample add 34 λ of the 14 per cent sodium carbonate, mix and add 40 λ of the 1.5 per cent ferricyanide solution. Mix the solutions thoroughly, fill the tube to the calibration mark with distilled water and place the tube into a boiling water bath for 3 minutes. After this period of heating, the tube is removed from the water bath, placed in cold water long enough to cool the contents, and the sample is transferred with a large capillary pipette to a porcelain titration dish, rinsing both the tube and the pipette 3 times with successive portions of about 40 λ of distilled water. To the contents of the dish, add 75 λ of 10 per cent sulfuric acid. Add a drop of the 0.1 per cent Setopaline C and titrate the ferrocyanide present with 0.0025 N ceric sulfate by means of the Drop Scale Burette. Carry each analysis through as quickly as possible (approximately 3 minutes is required from the time the sample is removed from the water bath to completion of titration). The first change from a canary yellow to a golden brown color is taken as the end point. The color change is very distinct, but it takes a considerable amount of practice in order to recognize it. A blank must be determined on the reagents, and the results of the blank used for the correction of the titration volumes.

It has been found that the time of heating requires some control (49). Heck, Brown and Kirk state that heating the sample between 2 and 10 minutes gives a reasonably constant factor, but less than 2 minutes results in incomplete oxidation and more than 10 minutes produces an unsatisfactory titration because of interference from the breakdown of the ferricyanide.

Calculation. In determining how much glucose is present in the sample, the titer of the blank is subtracted from that of the sample.

The conversion factor for transforming ϵ (microequivalents)[5] of ceric sulfate, to γ (micrograms)[6] of glucose is 37.58. This factor is empirical and may need to be redetermined by the operator to standardize his own technique. Thus: Volume of ceric sulfate x normality of ceric sulfate x 37.58 = γ glucose in the sample.

Results: Salivary samples of 16 cases were analyzed in this preliminary investigation. The results are listed in Table IV. Persons of both sexes, of varying ages, with and without caries were studied in Groups I and II. Group I, Table IV, contains 3 cases in which the teeth were first polished with unflavored flour of pumice by a dentist and a salivary sample taken 1 hour later. Group II, Table IV, contains 6 cases in which the teeth were brushed without a dentrifice and flossed. In Groups I and II, resting and activated samples were taken from the same individual in immediate succession.

In some cases more glucose was found in the activated than in the resting saliva, while in others the opposite results prevailed. In Group I, Table IV, the range of concentration of glucose in resting saliva in mg. per cent (14.04 to 23.04) is slightly higher than that of Group II (12.12 to 22.50), while the activated saliva ranges from 14.04 to 30.00 mg. per cent in Group I and from 16.20 to 27.00 mg. per cent in the other group.

The rate of secretion of glucose in resting saliva (calculated in mg./hr.) ranges from 1.34 to 10.37 in Group I and from 1.42 to 9.22 in Group II, while the activated saliva in both groups shows a higher glucose value per hour—12.03 to 16.53 (Group I) and 4.54 to 27.82 (Group II). In Group III, 5 edentulous cases were studied, which showed the presence of glucose in amounts comparable to those found in the first 2 groups. The mg. per cent values for resting saliva ranged from 11.28 to 28.08 and the mg./hr. range was from 1.60 to 4.87. It is interesting to note (Group IV) that an intravenous injection of glucose temporarily raised the salivary sugar.

Lower results have been obtained in other cases, but the values were not reported because the experimental error is greatly increased in samples in which the glucose concentration falls below 1 γ per sample.

It is assumed, as in all glucose determinations, that the reducing

[5] Microequivalent = 10^{-6} equivalents.
[6] Micrograms = 10^{-6} grams.

TABLE IV

Results of saliva glucose determinations by the drop scale method

GROUP	SEASON	CASE	SEX	AGE	RACE	OCCUPATION	SMOKING HABITS	DENTAL HEALTH	PREPARATION OF THE PATIENT	GENERAL HEALTH	BEFORE OR AFTER BREAKFAST	RATE OF FLOW		DEPROTEINIZATION	GLUCOSE			
												Resting, c.c./hr.	Paraffin activated, c.c./hr.		Resting saliva		Activated saliva	
															mg. %	mg./hr.	mg. %	mg./hr.
I	Summer	J. L.	♂	9	W	Student	No	Restorations, caries	Prophylaxis by a dentist	Good**	Before	45.00	85.68	Immediate	23.04	10.37	14.04	12.03
	Summer	M. R.	♀	16	W	Student	No	Restorations, caries	Prophylaxis by a dentist	Good**	Before	16.20	98.40	Immediate	14.04	2.27	16.80	16.53
	Summer	G. G.	♀	13	W	Student	No	Restorations, no caries	Prophylaxis by a dentist	Good**	Before	5.82	40.80	Immediate	23.04	1.34	30.00	12.24
II	Summer	G. J.	♀	23	W	Laboratory Technician	Yes*	Restorations, no caries	Brushed	Good**	Before	7.20	99.00	Immediate	19.68	1.42	24.60	24.35
	Summer	K. K.	♂	33	W	Dentist	No	Restorations, no caries	Brushed	Good**	Before	15.60	108.00	Immediate	22.56	3.52	16.20	17.50
	Fall	S. B.	♀	8	W	Student	No	Restorations, caries	Brushed	Good**	Before	14.40	66.00	Immediate	12.36	1.78	24.84	16.39
	Fall	M. B.	♀	6	W	Student	No	Restorations, caries	Brushed	Good**	Before	4.20	16.80	Immediate	14.28	0.60	27.00	4.54
	Fall	J. W.	♂	29	W	Dental Student	Yes*	Restorations, caries	Brushed	Good**	Before	14.00	132.00	Immediate	17.04	2.39	20.28	26.77
	Spring	J. A.	♂	24	W	Dental Student	No	Restorations, caries	Brushed	Good**	Before	18.00	97.50	Immediate	12.12	2.18	16.68	16.26
	Summer	G. S.	♀	35	W	Nurse	No	No restorations or caries	Brushed	Good**	Before	60.00	169.20	Immediate	15.36	9.22	16.44	27.82
III	Summer	A. W.	♀	49	W	Housewife	No	Edentulous	Mouth washed with water	Good**	Before	29.50		Immediate	16.50	4.87		
	Summer	B.	♂	60	W	Painter	Yes*	Edentulous	Mouth washed with water	Good**	Before	30.00		15 minutes after	12.72	3.82		
	Summer	M.	♂	69	W	Carpenter	Yes*	Edentulous	Mouth washed with water	Good**	Before	12.00		15 minutes after	28.02	3.37		
	Winter	K.	♀	50	W	Housewife	No	Edentulous	Mouth washed with water	Good**	Before	14.40		Immediate	11.28	1.62		
	Spring	S.	♀	50	W	Housewife	Yes*	Edentulous	Mouth washed with water	Good**	Before	12.00		Immediate	13.30	1.60		
IV	Winter	T.	♀	42	Y	Cleaner	No	Restorations, caries	Not brushed	Injections twice daily of 1000 c.c. of 10% glucose. Peptic ulcers. Atropine also given	After eating. Patient on a milk and beef broth diet	Immed. 4.80 30 min. 6.00 1 hour 25.80		Immediate	Immediate 46.08 | 2.21 30 min. after 31.80 | 1.91 1 hour after 22.92 | 5.91			

* No smoking on the morning the sample was taken.
** Without any obvious metabolic disorder.

substance determined in these salivary samples is glucose because we have used a reliable method of analysis and of deproteinization. We are fully aware that this assumption may not be correct and so are devising experiments to verify its correctness.

SUMMARY AND CONCLUSIONS

A critical survey of the literature dealing with the sugar analysis of saliva shows that little or none of the reported results are reliable. For this reason, the present investigation was undertaken with an ultra micro-method and with full cognizance of the many factors that tend to alter the concentration of glucose in a sample of saliva.

The results of this investigation show that the drop scale quantitative method developed by Heck, Brown and Kirk for the determination of glucose in a sample to amounts in excess of 1 microgram can be applied to mixed human saliva. In the saliva of 15 healthy individuals, 5 of whom were edentulous, a reducing substance was detected which is assumed to be glucose. The results, in these selected cases, ranged from 11.28 to 28.08 mg. per cent in resting saliva and from 14.04 to 30.00 mg. per cent for activated saliva. Therefore, it can be stated that saliva contains glucose under normal conditions.

The method described offers the possibility of not only measuring the amount of sugar actually present in saliva, but also of investigating the role of salivary sugars in the development of dental caries and the influence of sugar intake on local bacteria growth. So far there are very little experimental data which indicate the mechanism by which the carbohydrates may influence the caries process.

The number of experiments performed in this laboratory, as yet, is too limited in number to permit establishment of the normal range of salivary glucose levels, but work is being carried on to accomplish this aim.

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HUMAN SALIVA

X. Fluctuations of Calcium and Phosphorus Content of Resting Saliva[1]

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INTRODUCTION

A comparison of the results of salivary calcium and phosphorus analyses obtained by former investigators has revealed considerable variation (3, 4, 5, 6, 7, 8, 9, 28, 39, 40, 42); however, few attempts have been made to arrive at a better understanding of the many factors that produce such a variation. This might explain why ranges for salivary minerals have not yet been established that may be called "standards" for healthy individuals, i.e., persons without apparent metabolic disturbance. In fact, the results of salivary analyses cannot yet be referred to as "normal" or "pathologic", "low" or "high", or "relatively low" or "relatively high" for an individual of a given age.

The rates of flow of resting and activated salivas[2] for the same individual during one day, several successive days, and over a period of years, have been shown to fluctuate widely (6, 10, 41). The range of fluctuation depended mainly on the original level of rate of flow of R. S. and the duration of collection time. It was found that the lower the original rate of flow of R.S., the less the fluctuation but the higher the percentage increase of rate of flow due to activation. It is conceivable that such changes in the rate of salivary flow would affect significantly both the mg. percent and mg./hr. values of the calcium and phosphorus

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[2] The symbols "R.S." and "A.S." will be used to designate resting and activated saliva.

content and this might account, at least in part, for the great variation of published results.

HEIDENHAIN'S LAW

More than sixty years ago, Ludwig (31) and Heidenhain (22, 23) disclosed the fact that there are definite laws governing the secretion of water and of inorganic and organic constitutents of saliva. In 1851, Ludwig made the fundamental observation that electric stimulation of the chorda tympani causes changes in composition of the saliva of the submaxillary gland. He found that the content of soiids decreased considerably and that the organic content was affected to a much larger extent than the inorganic. Heidenhain in 1878 differentiated between secretory nerve fibers, the main function of which is to regulate the secretion of water and inorganic salts, and trophic fibers, which serve to mobilize organic constituents from the gland. He found that the chorda tympani consisted primarily of secretory fibers and only a small portion of trophic fibers, while the sympathetic nerve contained more trophic than secretory fibers. By this means, he was able to explain the antagonism between the effect of chorda tympani stimulation and that of sympathetic stimulation upon the activity of the salivary glands. Chorda saliva is generally very watery, abundant and low in its content of solids, while the sympathetic saliva is viscous, scant, and rich in organic materials. On the basis of these and other fundamental observations, Heidenhain established a new law of salivary secretion, namely, *that with increased speed of salivary secretion due to electric stimulation of specific nerve fibers, there is an increase in the concentration of solids*. He found that with stimulation, the amount of inorganic material increased initially to a maximum level of 0.5 to 0.6 per cent for submaxillary and 0.4 to 0.5 per cent for parotid saliva of dogs.

It has been shown furthermore that Heidenhain's law applies not only to stimulation by electricity, but also by drugs, such as pilocarpin. However, if the duct of the salivary gland is obstructed, Heidenhain's law no longer applies because a small amount of highly concentrated saliva is produced with an increased salt content (19). An analogy may be found in the assumed ability of the kidney tubules to increase the concentration of glomerular urine by the resorption of water.

These fundamental laws, which were based mainly on experimental observations on dogs, cats and rabbits, have been accepted generally and elaborated on by many physiologists, among others, Werter (38), Novi (32), Pavlov (33), Langley (29), Langley and Fletcher (30), Carlson (14), Carlson and McLean (15) and Babkin (1, 2). In spite of the fact that these fundamentals are well known in physiology, most dental investigators have not made use of them. Since Heidenhain's law requires that in the same individual the concentration

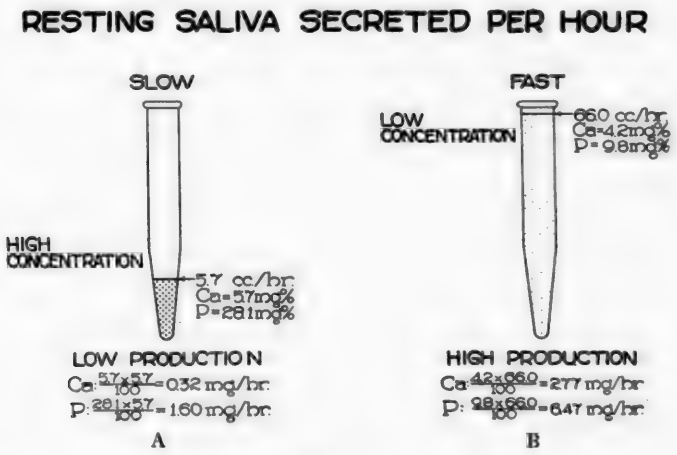

FIG. 1

(mg. per cent values) of solids increases with an increased speed of secretion, the question arises as to whether this law applies also to other conditions under which the salivary flow is altered, i.e., would individuals with high rates of flow have a greater concentration of calcium and phosphorus than those with lower rates of flow?

In routine salivary analyses the authors have frequently observed that slow flowing salivas had much higher calcium and phosphorus values than fast flowing salivas. Examples are given in *fig. 1*. The sample on the left side had a very slow rate of flow of R.S. (5.7 cc./hr.) and at the same time a comparatively high concentration (Ca

= 5.7 mg. per cent; P = 28.1 mg. per cent), while the sample on the right had a faster rate of flow of R.S. (66.0 cc./hr.) and a lower concentration (Ca = 4.2mg. per cent; P = 9.8 mg. per cent). It seems therefore, that the slower the rate of salivary secretion, the greater is the calcium and phosphorus concentration expressed in mg. per cent, and vice versa. As mentioned previously (9), practically all investigators have expressed their findings in mg. per cent values, as is done for instance, with blood serum, forgetting that the activity of the salivary gland may vary constantly. For this reason a consideration of the rate of secretion per time unit is indispensable. If the mineral content is expressed in mg./hr., i.e., per time unit or "rate of production" (*fig. 1*), less calcium and phosphorus are found per hour in the slowly flowing saliva, (0.32 and 1.60 mg./hr., respectively) than in the faster flowing one (2.77 and 6.47 mg./hr., respectively).

It is therefore obvious that if calcium and phosphorus mg. per cent values of slow and fast flowing salivas are compared without a consideration of the rate of secretion, any finding of a correlation or lack of correlation between salivary composition and dental caries or other oral diseases must be questioned. However, if the mg. per cent results are expressed together with the rate of secretion, the observations gain considerable value. Therefore, the following suggestions are made:

1. That the mg. per cent value be accompanied by the rate of secretion for one hour, as, for instance, for the right sample in *fig. 1:* $\text{Ca} = \frac{4.2 \text{ mg. per cent}}{66.0 \text{ cc./hr.}}$
2. That the mg./hr. value likewise be accompanied by the rate of flow; for instance: $\text{Ca} = \frac{2.77 \text{ mg./hr.}}{66.0 \text{ cc./hr.}}$

Even though the mg./hr. values of a series of analyses can be compared without considering the rate of flow, the value of 2.77 mg./hr. alone does not describe the entire condition, as this value could be obtained in different ways. For instance, in one case this figure may be arrived at by the calculation

$$\frac{4.2 \text{ mg. per cent} \times 66.0 \text{ cc./hr.}}{100 \text{ cc.}} = 2.77 \text{ mg./hr.};$$

in another individual, the same final figure may be obtained from entirely different values, e.g.,

$$\frac{8.4 \text{ mg. per cent} \times 33.0 \text{ cc./hr.}}{100 \text{ cc.}} = 2.77 \text{ mg./hr.}$$

It appears, therefore, that the calcium and phosphorus mg. per cent and mg./hr. values depend, to a large extent, upon the rate of secretion and it must be suspected that any fluctuation in the rate of flow (1) also would be reflected in the results. This question has been made the subject of the following investigation.

CALCIUM AND PHOSPHORUS CONTENT OF RESTING SALIVA ON DIFFERENT DAYS OVER A TWO-YEAR PERIOD

Over a period of one to two years, an average of five salivary samples were collected from 40 individuals. Twenty of these had a slow rate of flow of R.S. (less than 20 cc./hr., Group I) and the other 20 a higher rate (over 20 cc./hr., Group II). This arbitrary classification has been used previously to study in contrasting groups the fluctuations of rate of flow of R.S. (6) and A.S. (10, 41). The individual rates of flow for these two groups have been reported (6), with averages of 13.4 and 39.6 cc./hr.

The fluctuations of mg. per cent and mg./hr. values during the two-year period were calculated and expressed in averages[3] and percentages (Table I). The latter give a clearer picture of the changes in salivary secretion when the calculations for mg. per cent are compared with those of the mg./hr. values. It can be noted that the average calcium mg. per cent value for Group I is higher than that for Group II (5.99 as against 5.66 mg. per cent). Although this difference is not very pronounced, it indicates that a relationship exists between calcium content and rate of flow. A greater difference appears in the average mg. per cent phosphorus values of the two rate of flow groups (17.0 as against 11.8 mg. per cent).

The average mg. per cent fluctuations (Table I) for Groups I and II differ very little (Ca = 1.21 and 1.44 mg. per cent; P = 4.9 and 4.4 mg. per cent, respectively). Even though the average percentage fluctuations (percentage difference between lowest and highest result)

[3] The individual values are omitted because of limitation of space.

of mg. per cent calcium and phosphorus (Table I) show a difference between the two groups, with greater fluctuations in Group II (Ca = 24.8 as against 36.2 per cent; P = 35.5 as against 51.8 per cent), a closer analysis of the individual values revealed that one case in Group I was exceptionally high, while in Group II there were 3, thus raising the average of the latter considerably, and for this reason the differences must be questioned. It appears that the mg. per cent values are inversely related to the rate of flow, but the calculations of mg. per cent fluctuations do not seem to offer any decided difference between Groups I and II.

TABLE I

Averages and fluctuations of calcium and phosphorus mg. per cent and mg./hr. content of resting saliva on different days over a two year period

	GROUP	NO. OF CASES	MILLIGRAMS PER CENT			MILLIGRAMS PER HOUR		
			Average mg. %	Average Fluctuation		Average mg./hr.	Average Fluctuation	
				mg. %	%		mg./hr.	%
Calcium	I*	20	5.99	1.21	24.8	0.80	0.32	57.0
	II**	20	5.66	1.44	36.2	2.26	1.52	100.6
Phosphorus	I	20	17.0	4.9	35.5	2.21	0.89	56.7
	II	20	11.8	4.4	51.8	4.42	2.35	75.1

* Group I = rates of flow below 20 cc./hr.

** Group II = rates of flow above 20 cc./hr.

The *mg./hr.* calculations show, quite in contrast to the above observations, a decided difference between the 2 rate of flow groups (Table I). For calcium, the average mg./hr. value of Group I is about $\frac{1}{3}$ of that of Group II (0.80 as against 2.26 mg./hr.) and for phosphorus $\frac{1}{2}$ (2.21 as against 4.42 mg./hr.). Furthermore, the average mg./hr. fluctuation of calcium in Group I is less than $\frac{1}{4}$ of that in Group II (0.32 as against 1.52 mg./hr.) and for phosphorus about $\frac{1}{3}$ (0.89 as against 2.35 mg./hr.).

The average percentage fluctuation of mg./hr. calcium in Group I is about half of that of Group II (57.0 as against 100.6 per cent, respectively), but less pronounced for phosphorus (56.7 as against 75.1 per cent, respectively). It is striking to note that the average percentage

fluctuations for calcium and phosphorus mg./hr. values in Group I are practically the same (57.0 as against 56.7 per cent), while there is a decided difference in Group II (100.6 as against 75.1 per cent).

For practical purposes, it can be concluded that: 1, the lower the original rate of flow of R.S., the higher are the average mg. per cent and the lower the mg./hr. calcium and phosphorus values; which in respect to percentage composition is inconsistent with Heidenhain's law; 2, the fluctuations of mg./hr. figures are far greater than mg. per cent figures; 3, as was observed in the fluctuations of rate of flow of R.S. (6), Group I shows less fluctuations than Group II; 4, the rate of phosphorus secretion (mg./hr.) is far less influenced by an increase of rate of flow than is calcium. This manifests itself in a greater difference in the percentage fluctuation of calcium mg./hr. from Group I to II of 43.6 per cent (57.0 to 100.6 per cent) against only 19.4 per cent (56.7 to 75.1 per cent) for phosphorus. This spectacular difference, not disclosed in the mg. per cent calculations, emphasizes the necessity of mg./hr. calculations and the value of percentage fluctuations for an evaluation of salivary data.

CALCIUM AND PHOSPHORUS CONTENT OF RESTING SALIVA DURING 2½ HOURS OF CONTINUOUS COLLECTION

It has been reported previously (6) that the fluctuations of rate of flow of R.S. were greatly increased by extending the period of collection. For this reason, 4 individuals of Group I and 3 of Group II gave R.S. for 2½ hours (Table II). Samples were collected and measured separately every 15 minutes. When an amount was obtained that was insufficient for analysis, 2 or more samples were combined, thus giving from 2 to 9 samples for each individual. The average rates of flow in Groups I and II were 12.6 and 31.6 cc./hr., respectively.

The total calcium values average 5.79 and 5.16 mg. per cent for Groups I and II (Table II), and show again an inverse relationship to rate of flow. The inorganic phosphorus content shows a similar picture, with averages of 22.6 and 13.4 mg. per cent, respectively.

The mg. per cent fluctuations of calcium are practically the same for both groups (1.41 and 1.45 mg. per cent). However, for phosphorus, they are twice as high in Group I as in Group II (5.6 as against 2.8 mg. per cent).

The percentage fluctuations of the calcium mg. per cent values indicate that the lower the original rate of flow the lower the percentage fluctuations, although the difference is not very great (29.3 as against 34.8 per cent). For phosphorus, the great difference between the mg. per cent fluctuations in Groups I and II almost disappears in the calculation of percentage fluctuations (29.3 and 24.0 per cent). Surprisingly enough, the percentage fluctuations of mg. per cent calcium and phosphorus in Group I (Table II) are exactly the same (29.3 per cent), whereas in Group II they are higher for calcium (34.8 as against 24.0 per cent). The decreased fluctuation of phosphorus in Group II parallels the lower fluctuation of rate of flow (6) in the same group.

TABLE II

Averages and fluctuations of calcium and phosphorus mg. per cent and mg./hr. content of resting saliva during 2½ hours of collection

	GROUP	NO. OF CASES	MILLIGRAMS PER CENT			MILLIGRAMS PER HOUR		
			Average mg. %	Average Fluctuation		Average mg./hr.	Average Fluctuation	
				mg. %	%		mg./hr.	%
Calcium	I	4	5.79	1.41	29.3	0.76	0.42	88.9
	II	3	5.16	1.45	34.8	1.69	1.34	154.0
Phosphorus	I	4	22.6	5.6	29.3	2.84	1.64	82.5
	II	3	13.4	2.8	24.0	4.03	2.34	95.7

Again, a much more distinct difference between Groups I and II is noted in the mg./hr. values (Table II). While the mg. per cent fluctuations of calcium are practically the same for both groups (1.41 and 1.45 mg. per cent), the mg./hr. fluctuations in Group I are less than ⅓ of those in Group II (0.42 as against 1.34 mg./hr.). A similar difference, although not quite as great, is found for the mg./hr. fluctuations of phosphorus (1.64 as against 2.34 mg./hr.).

Although the percentage fluctuations of the mg. per cent values are not very different in the 2 groups, those for mg./hr. are much lower in Group I than in Group II, as was found during the 2 year period, and furthermore again it is found that the mg./hr. percentage fluctuations are much greater than percentage fluctuations of the mg. per cent values.

CALCIUM AND PHOSPHORUS CONTENT OF RESTING SALIVA DURING ONE HOUR OF CONTINUOUS COLLECTION

In most instances, a sufficient amount of R.S. for routine analytical work may be collected in a shorter period of time than 2½ hours; therefore, the fluctuations for the first hour (Table III) of continuous collection were recalculated from the values of Table II.

During the first hour of collection, only one case of Group I gave a sufficient quantity of saliva for more than one analysis, and, as this particular individual had the lowest calcium and phosphorus fluctuations (Table II), these figures are inadequate for comparative purposes. The influence of rate of flow, however, remains noticeable

TABLE III

Average and fluctuations of calcium and phosphorus mg. per cent and mg./hr. content of resting saliva during one hour of collection

	GROUP	NO. OF CASES	MILLIGRAMS PER CENT			MILLIGRAMS PER HOUR		
			Average mg. %	Average Fluctuation		Average mg./hr.	Average Fluctuation	
				mg. %	%		mg./hr.	%
Calcium	I	1	7.08	0.65	9.6	1.09	0.20	20.2
	II	3	5.45	0.95	19.3	1.89	0.73	44.8
Phosphorus	I	1	21.8	1.8	8.6	3.40	1.20	42.9
	II	3	13.4	1.2	9.8	4.30	1.33	37.4

as the average calcium and phosphorus values are higher in Group I than in Group II (Ca = 7.08 and 5.45 mg. per cent; P = 21.80 and 13.45 mg. per cent, respectively). As far as the average mg. per cent and percentage fluctuations of the 2 groups are concerned, it can be noted that they are proportionately almost the same as observed in the previous experiments which extended over 2 years and 2½ hours (Tables I and II). However, if one compares the average mg. per cent and percentage fluctuations occurring during 2½ hours with those during one hour (Tables II and III), it can be noted that they are far less in the shorter period of collection. It is therefore essential for the interpretation of salivary data that the time of collection be known.

The average mg./hr. calculations for one hour of continuous collection (Table III), as before, show that the lower rate of flow is accom-

panied by a lower calcium and phosphorus output, and vice versa (Ca = 1.09 and 1.89 mg./hr.; P = 3.40 and 4.30 mg./hr., respectively).

The mg./hr. fluctuations are again lower in Group I than in Group II for both calcium and phosphorus (0.20 as against 0.73 mg./hr. for calcium; and 1.20 as against 1.33 mg./hr. for phosphorus). While the percentage fluctuations of calcium mg./hr. are less in Group I than in Group II (20.2 as against 44.8 per cent), the phosphorus fluctuations are slightly greater in Group I (42.9 as against 37.4 per cent).

In practical terms, this means that during one hour of collection, patients with contrasting rates of flow have distinctly different rates of calcium and phosphorus secretion or excretion, and the slower the rate of flow, the higher are the calcium and phosphorus mg. per cent results. The mg./hr. values show a very striking difference, with greater fluctuations in the high rate of flow group. The fact that the mg./hr. fluctuations are far less during one hour of collection than during $2\frac{1}{2}$ hours makes it imperative for biological interpretation to know the original rate of flow and duration of collection time.

Summary and Conclusions, as well as *References to the Literature* are combined for this and the succeeding paper and appear on pages 643–648.

HUMAN SALIVA

XI. The Effect of Activation on Salivary Calcium and Phosphorus Content[1, 2]

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Heidenhain's law (23) stipulates that electric stimulation of salivary secretions in animals alters the composition of saliva in a definite way. In human beings, a relationship is found between the rate of flow of resting saliva and calcium and phosphorus content (11); however, it it is the reverse of Heidenhain's law in that mg. per cent calcium and phosphorus values decrease rather than increase with higher speeds of secretion, and vice versa. Because of this observation, the changes in salivary composition produced by paraffin activation were studied.

COMPARISON OF CALCIUM AND PHOSPHORUS CONTENT OF R.S. AND A.S.

The subjects for this study were divided according to the rate of flow of R.S. (11) into Groups I and II, each including 5 individuals with average rates of flow of 9.40 and 37.20 cc./hr., respectively. After the collection of a R.S. sample, each individual was required to chew a one-gram piece of paraffin for 8 successive periods of 450 chews each. The samples were measured and analyzed separately for each period; the total collection time averaged 45 minutes for each individual.

Table I presents the rates of flow and mg. per cent and mg./hr. values of calcium and phosphorus of the R.S. and first A.S. samples (average collection time 6–7 minutes). As a result of activation, the rate of flow increased markedly to 101.20 and 88.00 cc./hr. for

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Groups I and II. These two figures confirm previous findings that the percentage increase in rate of secretion from R.S. to A.S. is more pronounced in individuals with a low rate of flow of R.S. than in those with a fast flow (10).

Because of the difference of original rates of flow, the R.S. calcium and phosphorus mg. per cent values are decidedly higher in Group I than in Group II (Table I, Columns 1 and 3), namely, Ca = 6.21 as against 4.72 mg. per cent and P = 17.60 as against 12.00 mg. per cent. As a result of activation with an increased rate of flow, the calcium and phosphorus values drop in both groups approaching the same level (Ca = 4.32 and 4.17 mg. per cent; P = 10.60 and 11.10 mg. per cent,

TABLE I

Average rate of flow and calcium and phosphorus content of resting and activated saliva

	GROUP I*		GROUP II*	
	(1) Resting Saliva	(2) Activated Saliva (450 Chews)	(3) Resting Saliva	(4) Activated Saliva (450 Chews)
Rate of flow, cc./hr.	9.40	101.20	37.20	88.00
Calcium, mg. %	6.21	4.32	4.72	4.17
Phosphorus, mg. %	17.60	10.60	12.00	11.10
Calcium, mg./hr.	0.60	4.44	1.72	3.92
Phosphorus, mg./hr.	1.62	11.16	4.41	9.56

* Averages of five individuals each for Groups I and II.

respectively). These observations again emphasize the fact that activation conceals, to a large extent, differences in calcium and phosphorus composition which exist in R.S. samples of individuals with varying rates of secretion. Furthermore, the decrease of the mg. per cent values accompanying the increased rate of flow due to paraffin activation in the same individual also supports the suggested exceptions to Heidenhain's law.

The mg./hr. calculations (Table I) show the reverse picture: The slower the rate of flow of R.S., the smaller is the quantity of calcium and phosphorus secreted per time unit (one hour). The same holds true in the comparison of R.S. and A.S. Although, as a result of activation, the salivary glands produce lower mg. per cent concentrations of calcium and phosphorus, they are actually secreting a quantity

per time unit (considering the mg./hr. values) which is many times greater than that of R.S. These findings agree with those of a previous report (11) in which the relationship of rate of flow and calcium and phosphorus content of R.S. alone was tested.

If activation is continued over a longer period of time (45 minutes) and the samples collected separately for each 450 chews, the initial decrease of mg. per cent calcium content from R.S. to A.S. shows a tendency to continue in both groups (*fig. 1A*). Eight A.S. samples

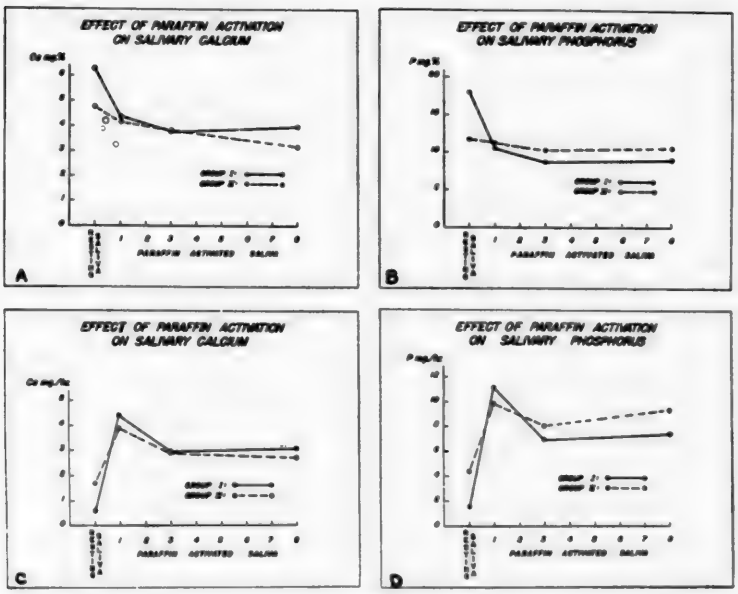
EFFECT OF PARAFFIN ACTIVATION ON SALIVARY CALCIUM
EFFECT OF PARAFFIN ACTIVATION ON SALIVARY PHOSPHORUS
EFFECT OF PARAFFIN ACTIVATION ON SALIVARY CALCIUM
EFFECT OF PARAFFIN ACTIVATION ON SALIVARY PHOSPHORUS
A
B
C
D

FIG. 1

were collected for each individual; only the first, third and eighth were analyzed for calcium and phosphorus. Difficulties were encountered in continuing the collection of saliva of 2 patients of Group I after the third sample. For this reason, the average values of the eighth sample represent only 3 individuals in Group I and explains the apparent leveling off of the last value as all of the individual figures actually decreased. The average mg. per cent phosphorus values (*fig. 1B*) show a tendency to remain at a constant level following the initial decrease with little distinction between the 2 groups.

The calcium mg./hr. changes (*fig. 1C*) show a pronounced increase from R.S. to A.S. (first sample). A decided decline can be noted after this and the values of both groups plateau at about the same level after the third period of activation. The phosphorus mg./hr. values (*fig. 1D*) follow a similar trend, although there is a slight tendency of both groups to rise in the eighth sample.

The percentage increase in rate of flow due to activation is marked (Table II); however, far less in Group II than in Group I, with a decided percentage decrease in mg. per cent calcium and phosphorus. These were again less in Group II than in Group I. When the percentage change of mg./hr. values are calculated, the reverse picture presents itself, i.e., with a higher rate of flow, due to activation, the

TABLE II

Percentage change of flow, and calcium and phosphorus content from resting to activated saliva

	GROUP I			GROUP II		
ACTIVATED SALIVA SAMPLE.....	1 %	3 %	8 %	1 %	3 %	8 %
Rate of flow, cc./hr.....	+1,185.0	+888.2	+923.2	+128.8	+128.4	+144.8
Calcium, mg. %.....	−30.7	−39.9	−42.7*	−14.0	−20.2	−33.8
Phosphorus, mg. %.....	−38.1	−47.0	−35.2*	−4.7	−12.1	−8.9
Calcium, mg./hr.....	+640.0	+396.7	+236.9*	+127.9	+69.2	+57.6
Phosphorus, mg./hr.....	+588.9	+334.0	+333.9*	+116.8	+82.1	+113.4

* In Group I the eighth sample was analyzed in only 3 of the 5 cases.

total production of these minerals per time unit is increased. This again is less in Group II than in Group I.

FLUCTUATIONS OF SALIVARY CALCIUM AND PHOSPHORUS DURING 45 MINUTES OF CONTINUOUS ACTIVATION

In a previous report (41), significant fluctuations in the rate of secretion were found during 45 minutes of activation, and it is to be suspected that such fluctuations would influence the calcium and phosphorus composition (Table III).

As far as calcium is concerned, the mg. per cent fluctuations (Column 2) during 45 minutes activation are far less in Group I than in Group II (0.73 as against 1.19 mg. per cent respectively). In percentage fluctuation (Column 3), the difference is even more marked (20.4 as against 42.7 per cent). This finding agrees in general with previous

observations on rate of flow fluctuations (41). The difference between Groups I and II in mg./hr. fluctuations (Column 5) of calcium is less pronounced, although the percentage fluctuations (Column 6) in Group I are slightly lower than in Group II (61.1 as against 76.4 per cent).

Quite in contrast to calcium, it can be noted that the phosphorus mg. per cent and mg./hr. fluctuations (Columns 8 and 11) are far greater in Group I than in Group II. Therefore, the general conclusion can be drawn that for individuals with slow rates of flow calcium shows less fluctuation during 45 minutes activation than for those individuals

TABLE III

Averages and fluctuations of calcium and phosphorus mg. per cent and mg. per hour content and rate of flow of activated saliva during continuous collection

PERIOD OF COLLECTION	GROUP	CALCIUM						PHOSPHORUS						RATE OF FLOW		
		milligrams per cent			milligrams per hour			milligrams per cent			milligrams per hour			Average	Fluctuations	
		(1) Average	(2) (3) Fluctuations		(4) Average	(5) (6) Fluctuations		(7) Average	(8) (9) Fluctuations		(10) Average	(11) (12) Fluctuation				
		mg. %	mg. %	%	mg./hr.	mg./hr.	%	mg. %	mg. %	%	mg./hr.	mg./hr.	%	cc./hr.	cc./hr.	%
45 Minutes	I*	3.91	0.73	20.4	3.50	1.60	61.1	9.5	2.4	27.3	8.75	4.22	62.6	86.6	34.3	60.9
	II	3.69	1.19	42.7	3.20	1.95	76.4	10.7	1.7	17.4	9.11	3.33	48.7	87.1	50.0	79.8
18 Minutes	I	4.04	0.56	15.6	3.72	1.49	58.2	9.4	2.2	25.3	8.93	4.22	62.6	90.7	30.3	52.4
	II	3.97	0.70	23.2	3.45	1.67	60.2	10.8	1.4	14.2	9.01	2.64	31.6	83.2	28.7	34.6

* Five individuals were included in each group.

with fast rates of flow, while for inorganic phosphorus this picture is reversed. If one compares the percentage fluctuations of mg./hr. calcium and phosphorus (Columns 6 and 12), it is surprising to note that they are about the same in Group I (61.1 and 62.6 per cent), while in Group II there is a marked difference (76.4 and 48.7 per cent). These findings must be duly considered in the establishment of standard ranges of salivary composition.

FLUCTUATIONS OF SALIVARY CALCIUM AND PHOSPHORUS DURING 18 MINUTES CONTINUOUS ACTIVATION

Since a sufficient amount of A.S. for analytical purposes is obtained in less than 45 minutes, i.e., during a period of 10 to 20 minutes, fluc-

tuations were calculated on the basis of the first 3 successive A.S. samples obtained during an average collection time of $18\frac{3}{4}$ minutes (Table III). The calcium mg. per cent and mg./hr. fluctuations are less in comparison to those during 45 minutes activation; the difference is not as marked for phosphorus. For practical purposes, this means that one must expect smaller fluctuations of mg. per cent and mg./hr. calcium values during a shorter period of activation, and these again are less pronounced in patients with a low rate of flow. These findings with A.S. parallel those on R.S. (11). Therefore, for the interpretation of results, it appears of great importance to know whether an individual has an originally slow or fast R.S. rate of flow and whether saliva was collected for a long or short period.

In the foregoing, an inverse relationship between mg. per cent calcium and phosphorus content and rate of flow and a direct relationship between mg./hr. values and rate of flow have been demonstrated. The determination of the fluctuations seems to be of great importance for the interpretation of salivary analyses. However, the question arises as to whether these fluctuations of calcium and phosphorus are solely the result of fluctuations of rate of flow or whether other factors have to be considered (12). It has been repeatedly shown that the mg. per cent concentration of other salivary constituents, total solids (43), ash (43), potassium (37), as well as enzymes (34), carbon dioxide capacity (17, 43), titratable alkalinity (17, 25, 27) and pH (25, 27, 43) actually increase with increased speed of secretion, due to activation, while calcium and phosphorus are exceptions as shown above and by others (24, 27, 37, 43).

It is known from cytological observations (13, 16) that the salivary cells in the resting state show microscopic bodies called mucinogen granules (granules of Langley) and zymogen granules (granules of Claude Bernard), depending on whether the cells are of the mucous or serous type. Upon activation, the granules of the salivary cells immediately break up into many very fine particles. This change presumably renders their contents (called precursor or secretion antecedent) available for the production of mucin or enzyme. The greater total surface presented by the granules after dividing may play a part in the secretion of the larger quantities of saliva produced during activation by increasing osmotic pressure through the release of salts

and secretion antecedent. This would explain the observation of greater A.S. values for total solids, ash, potassium, carbon dioxide capacity, titratable alkalinity and enzymes. This theory is borne out by the fact that the finely divided granules decrease in size and number as activation continues. As a possible explanation of the lower calcium and phosphorus values in A.S. and higher ones in R.S., it has been stated that the salivary gland in the resting state restores the granules and builds up their size to the former proportions. During this process, the gland may be said to be storing solids and mucin and enzyme precursors in the granules, but at the same time concentrating calcium and phosphorus into the salivary secretion. Upon activation, since calcium or phosphorus are not stored, they are literally washed out of the cell and are greatly diluted by the large volume of saliva produced. As activation continues, the levels of calcium and phosphorus drop further as they are more completely washed from the gland. A point, however, may be reached where the production of calcium and phosphorus per time unit does not decrease further.

COMMENT AND CONCLUSIONS

(*Including paper X of this series*)

The use of salivary analyses as a measure of the metabolic state of an individual and as an aid in the diagnosis of oral disease has been suggested for many years. Numerous attempts (18, 20, 21, 26, 35) have been made to establish some standard salivary test as an immediate measure of the activity of dental caries, but most of these have failed. The primary reason for the lack of correlation was the great variation in results obtained. However, surprisingly few investigators have attempted to find the reason for these variations. Even if inadequacies and deficiencies of technical procedure, variation in the state of health, age, sex, selection and classification of cases examined are disregarded, there still remains the fact that all previous investigators have expressed their results for calcium and phosphorus content of saliva in mg. per cent values only. It is the impression of the authors that for this reason alone all previous analytical work is valueless for comparative purposes.

For blood serum, the mg. per cent measure is applicable. However,

it is erroneous to believe that this same measure can be used in the study of a secretory or excretory product. For urine, it has been accepted generally that only the amounts excreted per time unit are comparable, and the same principle must be applied to saliva. As has been demonstrated previously (6, 10, 41), salivary flow varies considerably due to innumerable stimulating and depressing factors. It is quite obvious that the continuous change in rate of flow must be expected to affect salivary composition, resulting at one time in a more diluted saliva (with regard to certain minerals) and at another time in a more concentrated one.

For comparative purposes, it therefore becomes necessary to establish values that represent the amounts of calcium and phosphorus per time unit, and for this reason it is suggested that the results be expressed as mg./hr. values together with the rate of flow. If mg. per cent values are given, it becomes necessary to record also the rate of flow so that the mg./hr. values can be calculated.

Examination of the calcium and phosphorus results of individuals with contrasting slow and fast flowing R.S., as well as a comparison of calcium and phosphorus content of R.S., with paraffin A.S. of the same individuals, disclosed that Heidenhain's law apparently does not apply to these 2 elements but only to the total solids and certain of the inorganic and organic constituents of human saliva during paraffin activation and to the total solids of animal saliva during electric stimulation.

The changes produced by paraffin activation and the fluctuations of calcium and phosphorus content of R.S. and A.S. were studied, and the findings can be summarized as follows:

A. *Resting Saliva:*

1. If individuals are arbitrarily classified into 2 groups with slow and fast flowing R.S. (Groups I and II), it is found that the average calcium and phosphorus mg. per cent values are higher in Group I than in Group II, and indicates *an inverse relationship between these two minerals and rate of flow. The consistent repetition of this finding in all experiments indicates one possibility of explaining the differences in results reported by various investigators.*
2. Repeated analyses over a period of one to two years again reveal higher calcium and phosphorus mg. per cent values in Group I than in Group II, while the average mg. per cent fluctuations differ little in both groups. Quite in contrast to this, it is found that the mg./hr. values for both calcium and phosphorus are very much

higher in Group II than in Group I. The same holds true for the mg./hr. and average percentage fluctuations. For practical purposes, it can be concluded that the lower the rate of flow of R.S. the higher are the average mg. per cent and the lower the mg./hr. calcium and phosphorus values, which is the reverse of Heidenhain's law. Furthermore, the fluctuations, especially of mg./hr. values, are less in patients with slow rates of flow.

3. The great difference in average percentage rate of flow fluctuation (Ref. 6, Table I), between the two groups (which is lower for the lower rate of flow group over 2 years) is reflected in the average percentage mg. per cent and mg./hr. calcium and phosphorus fluctuations. For practical interpretation, therefore, it can be generally concluded that the fluctuations in calcium and phosphorus composition of saliva are, to a large extent, the result of fluctuations in rate of flow. These findings emphasize the difficulties one encounters in an attempt to study the effect of various exogenous or endogenous factors on salivary composition. Because in individuals with large fluctuations in rate of flow accompanied by equally large fluctuations in calcium and phosphorus composition, specific changes in salivary composition, due to medication, dietary changes, etc., are sometimes hardly detectable. Unfortunately, far-reaching conclusions in this respect have been reported by investigators who did not record the rate of salivary secretion. Therefore, individuals with low rates of flow are better test subjects over an extended period of time than others because of lower fluctuations.
4. During a 2½ hour collection period, similar values and relationships between the calcium and phosphorus content and rate of flow were found during the 2 year observation period. The average percentage fluctuations of mg./hr. calcium and phosphorus were slightly higher during the continuous collection period.
5. The fluctuations of rate of flow in Group I (Ref. 6, Table III) were decidedly higher than in Group II during 2½ hours, which is in contrast to the 2 year observation. This, however, is not reflected in the calcium and phosphorus mg. per cent values, which are equal for the 2 groups and in fact the mg./hr. values show greater fluctuation in Group II.
6. When the collection period is shortened to one hour, the mg. per cent and mg./hr. fluctuations in general are greatly reduced in both groups for calcium as well as for phosphorus. Therefore, in all salivary studies the time of collection must be known.

B. *Activated Saliva:*

1. If resting and activated saliva samples of the same individuals are compared with regard to mg. per cent and mg./hr. calcium and phosphorus results, it is found that as a result of activation Group I shows a greater increase in rate of flow than Group II. This is accompanied by a decided drop in calcium and phosphorus mg. per cent values in the activated samples. The reverse is true for the mg./hr. results. The great difference in calcium and phosphorus mg. per cent and mg./hr. values between Groups I and II is shown consistently again in the original R.S. values; however, the A.S. levels for these 2 groups are identical. This indicates that although a very useful classification of individuals on the basis of rate of flow can be made from the figures for R.S., activation obscures any differences between the individuals of these two groups not only with respect to rate of flow, but also calcium and phosphorus content.

2. The mg. per cent decrease of calcium and phosphorus as a result of activation is far greater in individuals with a slow rate of flow (Group I) than in those with a high flow, while the reverse is true for the mg./hr. values. This finding indicates the necessity of knowing the original rate of flow of R.S. whenever A.S. is studied.
3. When activation is continued for 45 minutes, the average mg. per cent and mg./hr. calcium and phosphorus values continue to decrease druing the first half of the longer period of activation; after this, the calcium values still tend to decrease slightly, while the phosphorus values level off. The levels of the 2 groups remain approximately equal and it appears possible that after long continued activation salivary composition may come to a constant level.
4. During continuous activation (45 minutes), the fluctuations for rate of flow and mg. per cent calcium are less in Group I than in Group II. This is reversed for phosphorus.
5. When the continuous collection period is shortened to 18 minutes, the calcium mg. per cent and mg./hr. fluctuations are reduced, while the phosphorus values in general are not reduced. Although the fluctuations of calcium and phosphorus composition of R.S. during 2½ hours collection are somewhat greater than those of A.S. during 45 minutes, the fluctuations of R.S. during one hour are very much less than those of A.S. during either 45 or 18 minutes collection. This again indicates the stability of R.S. during the usual periods of collection required for routine salivary studies.

These preliminary studies on a comparatively small number of cases make mandatory further investigations of the extent of the influence of rate of flow and activation on the calcium and phosphorus content of saliva before any interpretation of the results of salivary analyses can be given. They emphasize, however, the great importance of questions nos. 1, 4, 5, 6 and 8, raised in the previous report (6, p. 433).

Since A.S. composition differs greatly during each minute of collection, and its content depends on the duration of collection time and the amount and type of stimulus, it is difficult to obtain satisfactory analytical results from A.S. for comparative purposes. As different individuals do not respond in identical manner to activation, it is not possible to standardize the degree of stimulation or arrive at a standard time of collection. At best, R.S. is not an unvarying product, but it does not fluctuate in composition during short periods of collection to the great extent that A.S. does. Resting saliva is produced during a period of least change in the state of the salivary gland.

In addition to the fact that in human beings the response of the salivary glands to paraffin activation in respect to mg. per cent calcium and phosphorus does not follow Heidenhain's law, the above data

indicates that paraffin A.S. (as collected under the conditions noted in the literature to date) does not seem suitable for comparative purposes.

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FLUORINE THERAPY FOR EXPOSED DENTIN AND ALVEOLAR ATROPHY[1]

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Dentin, which makes up the bulk of the tooth, is entirely internal, topographically. In the crown, the relatively impermeable enamel covers it and in the root portion, the cementum and the surrounding tissues afford protection. The gingiva, especially the gingival margin, is more readily permeated than enamel or even skin.

The exterior protecting barriers may be penetrated by anatomic changes in enamel (caries, fracture, attrition, abrasion, erosion or operative procedures), by functional changes (hyperesthesia from increased enamel permeability), by exposure of the dentin in the cervical area or by other defects at that point. Pulp removal, by amputation or, especially, extirpation, exposes the more vulnerable young dentin. All of these conditions lead to practically identical phenomenon, i.e., dentin exposure or exposed dentin. Exposed dentin, like any bone tissue, cannot endure long contact with external media without pathologic change such as hyperesthesia, infection and decay. The term, exposed dentin, characterizes the pathologic condition for all complete or partial losses of the protective barrier of dentin.

Since the pathologic phenomena in exposed dentin are so similar, a single therapy should be sought. The problem is to lower the permeability, and thereby the susceptibility and vulnerability, of the exposed tissue by forming a more or less effective surface barrier. Artificial production of a zone similar to natural hypercalcification in vital teeth should be possible for vital and pulpless teeth. Fluorination has been utilized to produce such a barrier.

Fluorine has not been used in medicine chiefly because of its toxicity although homeopaths use small doses to treat skeletal diseases and

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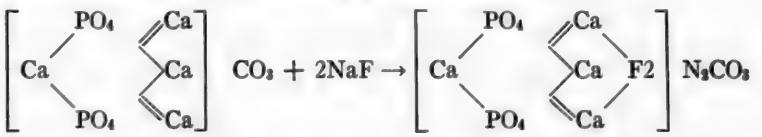
as an antispasmodic. The fatal dose of sodium fluoride is 0.16 gm./kilo of body weight.

FLUORINATION OF DENTIN

Weak isotonic solutions of sodium fluoride are introduced on a pellet of cotton into the tooth cavity in 0.07 mg. amounts. After the root canal is filled a paste containing 0.35 mg. of NaF is placed in the cavity. In surface applications of fluorine to the dentin 0.012 gms. of NaF are used, one fourth entering the dental tissues and the remainder being removed. The paste adheres well to the tooth surface insuring against accidental dropping into the oral cavity. These doses are non-toxic.

Investigation has demonstrated that sodium fluoride is readily absorbed by the dental hard tissues. Intact teeth absorb 3.6 to 6.7 mg. of fluorine per gram of tooth substance submerged in a 0.7 per cent NaF solution; carious teeth absorbing as much as 10 mg. per gram of tooth substance. About 50 per cent of the absorbed fluorine forms an insoluble compound with tooth substance, fluorine adsorbing on the walls of dentinal tubules as well as on the surface of calcium. The rate of fluorine absorption is independent of the moisture content of the tooth.

The fluorine treatment results in partial replacement of complex $CaCo_3$ and formation of hard insoluble calcium fluoride. (Table I and *figs. 1* and *2*) The reaction is approximately:



Histologic research has also demonstrated the absorption of fluorine by dentinal tubules and basic substance. The formation of uniformly colored, regular spheres are clearly distinguishable against the background of fluorosed dentin. Histologic sections of fluorosed teeth show replacement of calcium salts creating new physical barriers. These studies indicate that the leaving of 0.7 per cent NaF paste in the tooth results in hardening of softened, carious dentin. Histologically the sodium fluoride is demonstrable (*fig. 3*). Silver staining

demonstrates the decrease in dentin permeability after NaF treatment. Hardness of $CaCO_3$ in Mohs scale is less than that of CaF_2. The increase in hardness and permeability resistance permits the hy-

TABLE I

The amount of NaF (mg) absorbed per gr. of the dental tissue

	TEETH DECALCIFIED					TEETH NOT DECALCIFIED						
	Caries			Intact		Caries		Intact				
Weight	6	6	6	7	1	8	6	1	6	8	5	5
Time of analysis	0.680	0.500	0.460	0.870	0.500	1.150	1.000	0.700	1.750	1.420	1. 30	0.920
5 days	0	0	0	0	0	7.6	5.0	8.0	3.5	4.4	6.0	6.7
9 days	0	0	0	0	0	8.6	8.0	9.0	3.5	4.4	6.0	6.7
15 days	0	0	0	1.4	1.4	8.6	9.0	10.0	3.5	4.4	6.0	6.7
20 days	0	0	0	1.4	1.4	8.6	9.0	10.0	3.5	4.4	6.0	6.7

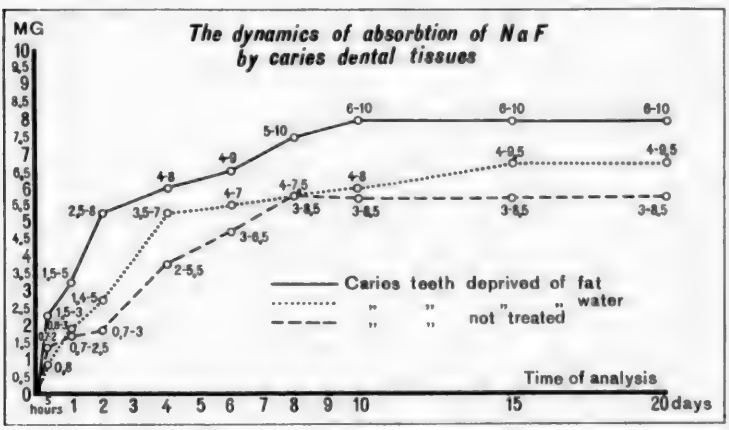


FIG. 1

pothesis that the reticular density of the crystal facets is increased with higher frequency of particles in the radiographic grate.

Clinical observations have shown a hardening of softened dentin in caries during a period of several weeks under a 0.7 per cent NaF paste. A thicker border layer of increased radiopacity was observed radiographically after fluorination of the root canal. Carious dentin,

probably because of changes in its physical structure, absorbs more fluorine than sound dentin but in deep caries hypocalcification stops the absorption of fluorine.

By fluorination of dentin a denser grate in its crystalline structure, a decrease in permeability and, thus, a barrier functionally equivalent to the physiological zones of hypercalcification are produced.

In clinical practice fluorine is applied for hyperesthesia at the gingival area, functional and anatomic inefficiency of enamel, exposure of

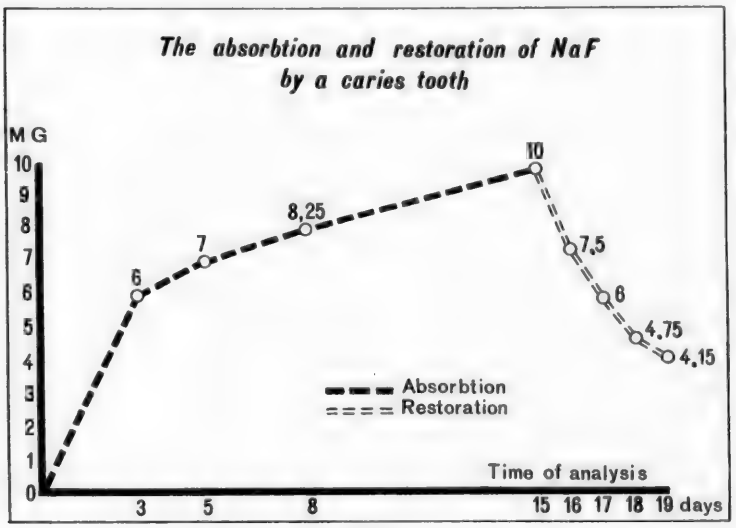
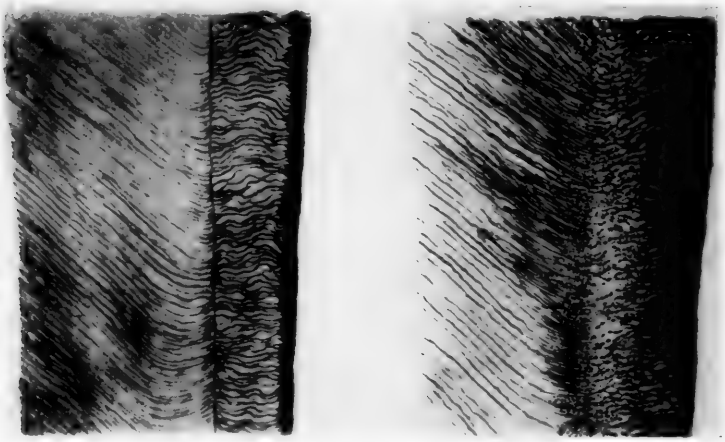


FIG. 2

dentin by grinding and for tooth fractures. Different conditions require different methods of fluorine application. Three methods have been utilized: 1. As an isotonic (0.7 per cent) solution NaF is applied on cotton pellets 2 or 3 times in 10 to 20 days for root canals. 2. A paste made from white clay with 0.7 per cent NaF is used for filling root canals and dressing amputated or extirpated pulp stumps. The small bismuth content makes it radiopaque. With addition of zinc oxide the same paste can serve as a protector in filling cavities. 3. A hypertonic solution or paste (31–75 per cent) in glycerine base is used as an unction for sensitive gingival areas ground off in cavity prepara-

tion. The increase in NaF content for anesthetizing dentin is not intended to utilize osmosis which can be of little value in the transitory application of the paste but, rather, to accelerate and increase the combination of fluorine with dentin.

Clinical tests of NaF preparations for treatment of exposed dentin are recognized as successful in immediate results and after one or two years. According to the clinical condition fluorine acts as an anesthetic or conservant of dentin. It also conserves pulp remnants left



A B

FIG. 3. In dentinal tubules and in basic substance, after NaF treatment great numbers of uniformly colored regular spheres are evident. A—before treatment, B—after treatment.

after amputation or extirpation, increasing the possibility of saving the pulp. In pulps exposed by caries, sodium fluoride is not effective and mechanical and antiseptic treatment is still used. It is recommended that roots of teeth to be replanted, transplanted or implanted be treated to avoid resorption. In deciduous teeth fluorination is not used because of its retarding effect on the physiologic process of resorption.

FLUORINE ANESTHESIA FOR DENTIN

The pain caused by operative procedures, erosion, abrasion, clasps, exposed gingival dentin and hypersensitive dentin in most cases can

be eliminated by fluorin. Previous efforts have been directed at the organic elements of the pulp, whether it be by cauterization, anesthetic or lipid dissolving drugs. The method of fluorination is aimed at blocking the pain receptors, indirectly, through the inorganic substance of the tubule wall. As the tubule walls absorb fluorine the density of the crystals is increased and the lumen is narrowed. The result is not, strictly speaking, an anesthesia but is production of an insulation. The sensitiveness is eliminated only in the area treated by fluorine and is reestablished when the fluorinated layer is removed. The pulp is unaffected.

The preferred technic of application is rubbing in about 17.2 mg. of a 75 per cent NaF paste. This contains approximately 12.9 mg. of NaF, one quarter of which is absorbed by the tooth. The excess paste is removed and in several hundred cases no necrosis of the pulp has resulted nor has there been evidence of general intoxication from occasional swallowing of the paste. In periodontosis with marked alveolar atrophy, fluorin treatment is contraindicated because it may cause prolonged pain.

In treatment of sensitive dentin in cavities, 31 per cent NaF paste (NaF—1; white clay—1; glycerine—1.2) is used. In cases of deep caries not over 1 per cent NaF is used because the superfluous fluorine does not combine with the thin layer of dentin. The paste is rubbed 2, 3 or more times and the paste is left in for 15 to 30 minutes. Removal of the paste before proceeding is optional. The remaining 0.7 per cent NaF paste in a deep cavity does not cause pulpal irritation or necrosis nor any symptoms of general intoxication. When the paste is applied externally the gingival area should be well washed and the tooth rinsed.

The technic of fluorin anesthesia during cavity preparation is more simple than the application of Hartman's solution and its efficiency is *ca.* 96.2 per cent. The use of fluorin in treatment of hypersensitive dentin is the most effective and lasting method. It increases the physical and chemical durability of the fluorinated areas of dentin and does not burn the mucous membranes.

FLUORINE TREATMENT OF ROOT CANALS

Dentin exposed by pulp amputation or extirpation is adjacent to soft, vulnerable tissues. In these cases the dentin may be inhabited,

to a certain depth, by microorganisms. In chemical treatment of root canals the soft tissue adjacent to the exposed dentin should be conserved. Sodium fluoride treatment meets this requirement, does not coagulate the albumen and walls off the microorganisms in the infected dentin.

An isotonic (0.7 per cent) solution of NaF is used to wash the root canals after removal of their contents and white clay paste (0.7 per cent NaF) is used for covering pulp stumps and filling root canals. The clinical technic used does not interfere with absorption of sodium fluoride by the dentinal walls. The cotton pellet applied into the

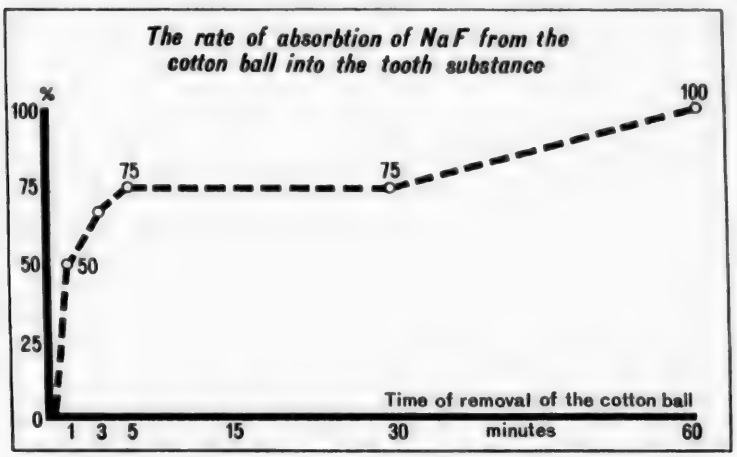


FIG. 4

canal is well saturated with the isotonic NaF solution (0.01 cm.^{3}) and from 75 to 80 per cent of this is absorbed after a period of 3 minutes (*fig. 4*). Application of 0.7 per cent NaF solution decreases the permeability of the dentin. This is demonstrated by comparison of 2 halves of the same root, silver nitrate diffusing more slowly in the fluorinated dentin. Bacteriologically it has been shown that the growth of bacteria, freed from the decayed pulp into the root canal treated 3 times with 0.7 per cent NaF solution, was oppressed, the bacteria present are more saprophytic and the number of bacterial types is reduced. This 0.7 per cent NaF is not toxic but is isotonic with blood serum.

From thousands of dispensary cases treated for pulpitis or periodontosis with sodium fluoride, complications requiring surgical interference have occurred in less than 2 per cent. The results after some duration have been clinically favorable. After the paste has been kept in the tooth for 3 months, degrees of restoration of the gingival crevice and increase in thickness of the alveolar bone in granulating periodontosis has been observed, sometimes in pulpitis, with the aid of radiographs. It has been demonstrated that sodium fluoride treatment for root canals produces mild antisepsis which neither coagulates the pulp stump nor irritates the periodontium but does increase the density and impermeability of the root canal walls.

In root canal filling a paste of sodium fluoride (0.11), white clay (7.0) and bismuth (3.0) with glycerine is used. This paste is highly plastic, easily applied, adherent to the walls, seals the root dentin for a long time and is readily distinguished on radiographs. In children's teeth it has been found to resorb readily from the periapical tissues in a period of several weeks and in adults' mouths after 3 months. The paste does not resorb from the root canal in spite of its ready disappearance from the periodontal tissue. The advantages over cement are the preservation of its plasticity, resorption from periapical area, greater chemical activity and simple introduction or removal.

FLUORINE THERAPY FOR PROGRESSIVE ALVEOLAR ATROPHY

Progressive alveolar atrophy is a difficult type of periodontosis to treat. Especially difficult are those instances where teeth become loosened and lost with increased physical strain on other teeth leading to secondary traumatic atrophy. In determining the atrophy by Gelman's method it is believed that even within 1st degree atrophy the masticating capacity is diminished. Only cases of 1st and 2nd degree atrophy are considered satisfactory for treatment; the presence of 3rd degree atrophy or of unremediable forms of occlusal trauma justify classification as incurable.

The radiographic picture must be properly evaluated before deciding on therapy. In many instances the radiograph may reveal a greater loss of alveolar bone than it is possible to deduct on the basis of clinical examination. A careful study of reduced x-ray pictures

often shows the sound contour of the bone within the defect. Atrophy, in these cases, has generally taken place by decalcification of bone with preservation of the basic collagenous substance.

To recalcify the collagenous remnant of the alveolar bone that has been rarified during periodontosis the author proposes administering small doses of sodium fluoride (not over 0.01 gm. per day) internally by mouth. Observation of its influence on bone and tooth tissues, and study of the literature on mineral metabolism, permits classification of sodium fluoride as a periodontropous compound, i.e., a medicament that in given amounts and under given conditions has a selective curing effect on the tissue affected with periodontosis. Fluorin enters the organism mostly with the vegetable foods which always contain a certain amount of it. When introduced in larger doses fluorin is deposited chiefly in the teeth and bones and then in the thyroid gland and kidneys. In birds and animals fluorin settles in the ectodermal derivates. If introduced with lipoids as an organic compound fluorin deposits in cardiac muscle. Fluorin is absorbed with difficulty and is excreted mostly in the urine. The retention of fluorin depends on the metabolic processes. The lower the metabolic rate, the longer fluorin is detained in the tissues. The function of fluorin has not been accurately determined. It produces some effect on the thyroid gland, reducing the intensity of its hormonal activities. Enteral or parenteral introduction of sodium fluoride reduces the basic metabolic rate and removes other symptoms of thyroid function. Other halogens influence the metabolic process—iodine, bromine and chlorine. It can be supposed that fluorides in the tissues act as regulators for cell respiration. Embden and his pupils have found that fluorin, in certain concentrations, strongly contributes to the synthesis of *hexose-phosphate* from phosphoric and lactic acids in muscle tissue. Ewig, who investigated the influence of fluorine on cellular exchange in organs and tissue in culture media has shown that sodium fluoride possesses a dominant influence on the glycolytic ferment of cells in concentrations that have much less effect on cell respiration. In Ringer's solution, deprived of calcium, Ewig found the action of fluorin stronger because calcium reduces the toxicity of fluorin.

There is ground to believe that the different theories of the mechanism of sodium fluoride activity do not exclude but, rather, comple-

ment each other. Tchernigovsky, who has studied the effect of sodium fluoride on the striated muscle of cold blood animals, and others, express the opinion that fluorin suppresses the activity of ferments. Recently, the view that fluorin is a substance with the specific function of contributing to the binding of calcium by tissues, particularly by bone, was supported by the work of L. Michaelis. He considers that the presence of a certain amount of fluorin in the tissues is necessary for the deposition of calcium salts. Of great interest, in view of the author's work, is the enteric administration of sodium fluoride as a medicament acting specifically on the parathyroid glands.

One hundred and ninety cases of periodontosis have been treated with sodium fluoride and examined clinically and in addition several hundred cases have been attended in dispensaries. All patients have been examined after a period of a month and in 60 individuals during the following 6 to 12 months. The effectiveness of the treatment was determined by comparing the mobility of the teeth. In 50 individuals masticatory tests were given before and after treatment and in several patients who had received fluorin over a long period the serum calcium and blood coagulation time was determined.

The method of treatment was to remove the stains from the teeth and prescribe a 1 per cent solution of pure sodium fluoride for a period of 30 days (5 drops 3 times per day or 8 drops before meals 2 times a day). In the cases of acute purulent periodontosis an addition treatment of pockets was performed. The results were quite satisfactory. In all instances of 1st degree atrophy the teeth were completely strengthened and in the 2nd degree cases the atrophy was usually completely cured, in others decreased by 1 unit. In almost all cases the masticating ability was increased, the gingival inflammation either disappeared or diminished considerably and bleeding stopped. The disappearance of such subjective symptoms as itching of the gingiva and apprehension in chewing were also recorded. In singular cases the patients pointed out improvement in general health and elimination of headache and nail brittleness.

Not a single case of fluorin intoxication has been recorded. The coagulation time of the blood of patients under sodium fluoride therapy did not change nor did the serum calcium, determined only in patients with normal calcium contents, even after a long and regular

intake of 15 drops of 1 per cent sodium fluoride daily. Observations on a large number of patients (over 500) who had been taking the therapeutic dose of sodium fluoride permit the statement, with great assurance, that these doses taken daily for a period of 1 or 2 months do not result in any toxic phenomena.

CONCLUSION

Erlich's belief that a medicament can act only on those tissues with which it is connected has been the starting point in the search for therapeutic agents. The sodium fluoride method of treatment for exposed dentin and alveolar atrophy complies with this principle. The chemical receptor which stimulates the fixation of fluorin in the dental tissues and bones is calcium.

Due to difficulties of communication it has been necessary to omit the author's references to the literature.—ED.

SUPPLEMENT

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[1] The proceedings of the nineteenth general meeting (St. Louis, March 15–16, 1941) were published in the *J. D. Res.*, 20: 217, 1941 (this volume).

[2] *Sectional Meetings in 1940–1941* were held on the following schedules as reported by sectional secretaries. *Boston*—Oct. 27, Dec. 1, Jan. 26, Mar. 2, April 27. *Chicago*—Oct. 11, Nov. 8, Dec. 13, Jan. 10, April 11. *New York*—Jan. 28, May 27. *Philadelphia*—Nov., April. *Pittsburg*—Dec. 16, March 3, May 5. *St. Louis*—Nov. 28, Mar. 15. *Washington*—Dec. 12, Feb. 10, April 8.

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Not residents of North America and not now members of a Section—J. L. Boots, Ove Brinch, Knud-Mogens Christopherson, Gyula Csernyei, C. D. M. Day, Guido Fischer, S. F. Gottlich, Walter Hess, R. E. T. Hewat, J. J. Holst, G. Y. Hildebrand, Frode Hilming, Humphrey F. Humphreys, T. E. de Jonge-Cohen, Gustav Korkhaus, G. D. Macphee, Maurine W. Müller, Pekka Nironen, Silvio Palazzi, P. O. Pedersen, Paul Pincus, Friedrich Proell, F. M. Pucci, Ingjold Reichborn, Elkan Sanders, Guttrom Toverud, Rudolph Weber, J. J. Wolfe, H. K. Worner—29.

Total number of members as of Dec. 1, 1941—558.

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[1]Abbreviations—I. A. D. R.: International Association for Dental Research; J. D. R.: Journal of Dental Research.

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